The Effects of

Nuclear Weapons

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Editor

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Foreword

This handbook, prepared by the Armed Forces Special Weapons Project of the Department of Defense in coordination with other cognizant government agencies and published by the United States Atomic Energy Commission, is a comprehensive summary of current knowledge on the effects of nuclear weapons. The effects information contained herein is calculated for yields up to 20 megatons and the scaling laws for hypothetically extending the calculations beyond this limit are given. The figure of 20 megatons however is not to be taken as an indication of capabilities or developments.

CHARLES E. WILSON
Secretary of Defense

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Chairman
Atomic Energy Commission

THE FEDERAL CIVIL DEFENSE ADMINISTRATION commends this publication as the definitive source of information on the effects of nuclear weapons for the use of organizations engaged in Civil Defense activities. Its detailed treatment of the physical phenomena associated with nuclear explosions provides the necessary technical background for development of countermeasures against all nuclear effects of Civil Defense interest.

VAL PETERSON
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Federal Civil Defense Administration

Acknowledgment

At the request of the Atomic Energy Commission, the Armed Forces Special Weapons Project prepared this book with the assistance of the Commission. Dr. Samuel Glasstone was responsible for the compiling, writing, and editing and, largely, for its successful completion.

Assistance in the preparation and review of the book was provided by individuals associated with the Atomic Energy Commission, the Department of Defense, the Federal Civil Defense Administration, and their contractors.

DUCTILITY

3.73 The term ductility refers to the ability of a material or structure to absorb energy inelastically without failure; in other words, the greater the ductility, the greater the resistance to failure. Materials which are brittle have poor ductility and fail easily.

3.74 There are two main aspects of ductility to be considered. When a force (or load) is applied to a material so as to deform it, as is the case in a nuclear explosion, for example, the initial deformation is said to be "elastic." Provided it is still in the elastic range, the material will recover its original form when the loading is removed. However, if the "stress" produced by the load is sufficiently great, the material passes into the "plastic" range. In this state the material does not recover completely after removal of the stress, that is to say, the deformation is permanent, but there is no failure. Only when the stress reaches the "ultimate strength" does failure, i. e., breakage, occur.

3.75 Ideally, a structure which is to suffer little damage from blast should have as much elasticity as possible. Unfortunately, structural materials are generally not able to absorb much energy in the elastic range, although many common materials can take up large amounts of energy in the plastic range before they fail. The problem in blast-resistant design, therefore, is to decide how much permanent (plastic) deformation can be accepted before a particular structure is rendered useless. This will, of course, vary with the nature and purpose of the structure. Although deformation to the point of collapse is definitely undesirable, some lesser deformation may not seriously interfere with the continued use of the structure.

3.76 It is evident that ductility is a desirable property of structural materials required to resist blast. Structural steel and steel reinforcement have this property to a considerable extent. They are able to absorb large amounts of energy, e. g., from a blast wave, without failure and thus reduce the chances of collapse of the structure in which they are used. Steel has the further advantage of a higher yield point (or elastic limit) under dynamic than under static loading.

3.77 Although concrete alone is not ductile, when steel and concrete are used together, as in reinforced-concrete structures, the ductile behavior of the steel will usually predominate. The structure will then have considerable ductility and, consequently, resistance to blast. Without reinforcement, masonry walls are completely lacking in ductility and readily suffer brittle failure, as stated above.

The curves show the variation of peak overpressure with distance for a 1 KT surface burst and for a 1 KT free-air burst (based on the $2W$ assumption in § 3.94) in a standard sea level atmosphere.

Scaling. For yields other than 1 KT, the range to which a given overpressure extends scales as the cube root of the yield, i. e.,

$$d = d_0 \times W^{1/3},$$

where, for a given overpressure,

d_0 is the distance from the explosion for 1 KT,

and

d is the distance from the explosion for W KT.

Example

Given: A 1 MT surface burst.

Find: The distance to which 2 psi extends.

Solution: From Fig. 3.93 the cube root of 1000 is 10. From Fig. 3.94a, a peak overpressure of 2 psi occurs at a distance of 0.53 mile from a 1 KT surface burst. Therefore, for a 1 MT surface burst,

$$d = d_0 \times W^{1/3} = 0.53 \times 10 = 5.3 \text{ miles.} \quad \textit{Answer}$$

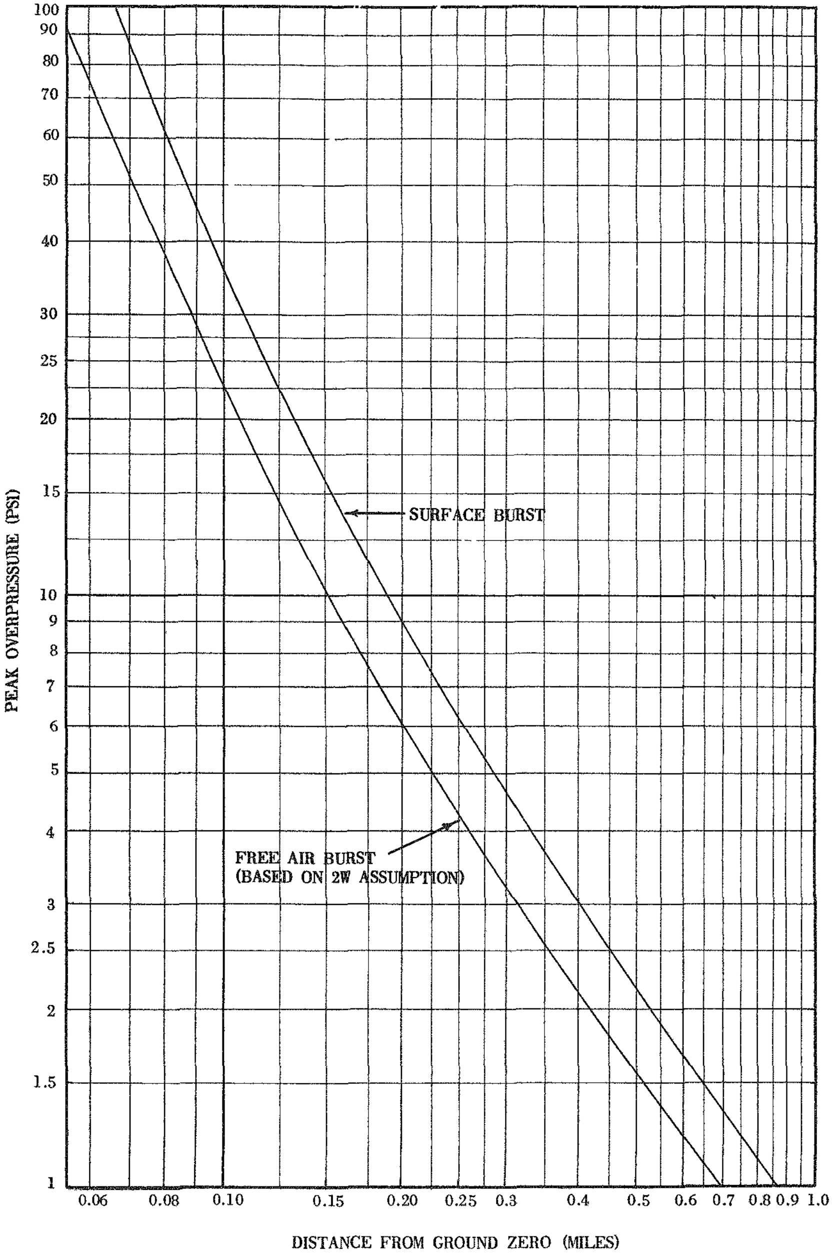


Figure 3.94a. Peak overpressure for a 1-kiloton surface burst and free air burst.

The curve shows the variation of peak overpressure on the surface with distance from ground zero for a 1 KT typical air burst in a standard sea level atmosphere under average surface conditions.

Scaling. For yields other than 1 KT, the range to which a given overpressure extends scales as the cube root of the yield, i. e.,

$$d=d_0\times W^{1/3},$$

where, for a given peak overpressure,

d_0 is the distance from ground zero for 1 KT,

and

d is the distance from ground zero for W KT.

Example

Given: A 1 MT typical air burst.

Find: The distance from ground zero to which 8 psi extends.

Solution: From Fig. 3.93 the cube root of 1,000 KT is 10. From Fig. 3.94b a peak overpressure of 8 psi occurs at 0.28 mile from ground zero for a 1 KT typical air burst. For a 1 MT typical air burst, therefore,

$$d=d_0\times W^{1/3}=0.28\times 10=2.8 \text{ miles.} \quad \textit{Answer}$$

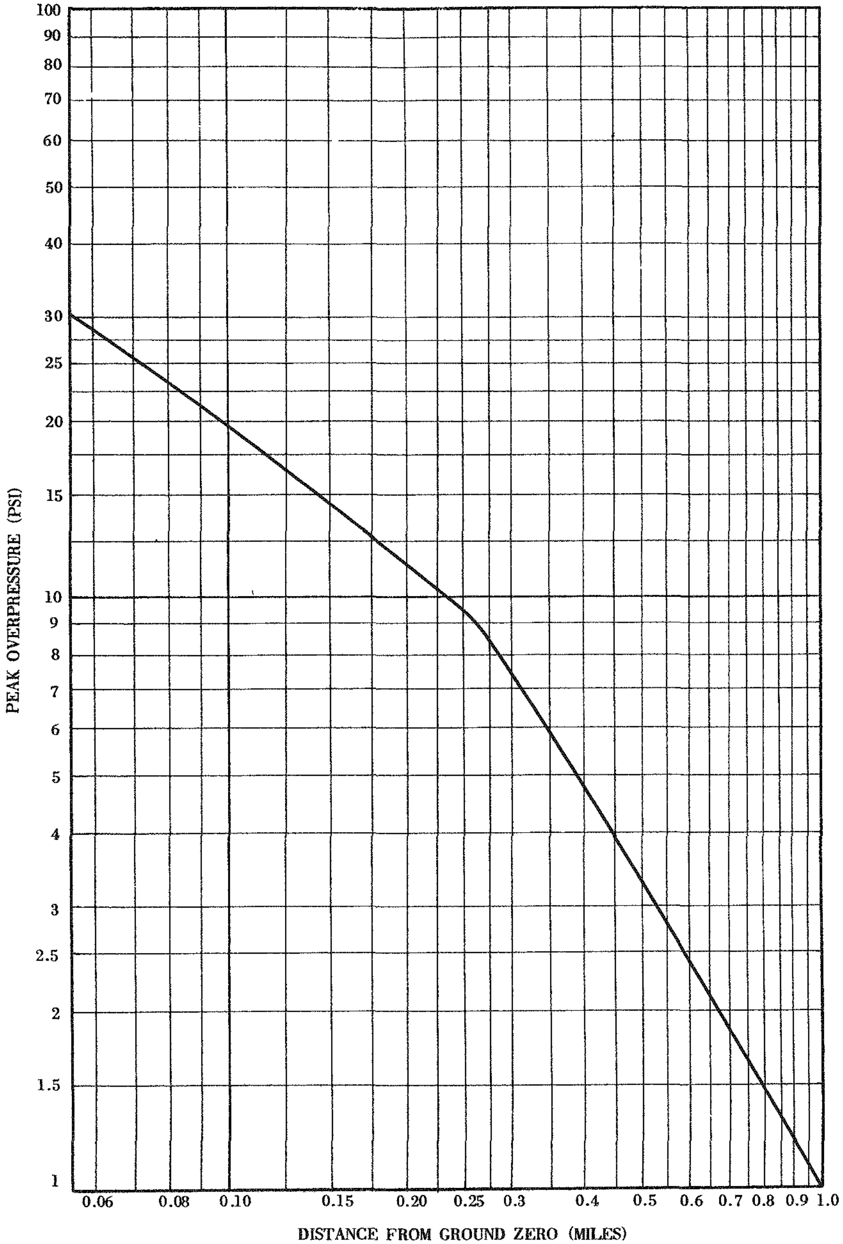


Figure 3.94b. Peak overpressure on the surface for a 1-kiloton typical air burst.

The curve shows the increase in height of the Mach stem with distance from ground zero for a 1 KT typical air burst in a standard sea level atmosphere under average surface conditions.

Scaling. For yields other than 1 KT, the height and distance of the Mach stem scale as the cube root of the yield, i. e.,

$$h=h_0 \times W^{1/3} \text{ at } d=d_0 \times W^{1/3},$$

where

h_0 is the height of Mach stem at a distance d_0 for 1 KT,

and

h is the height of Mach stem at a distance d for W KT.

Example

Given: A 1 MT typical air burst.

Find: (*a*) The distance from ground zero at which the Mach effect commences.

(*b*) The height of the Mach stem at 2.75 miles from ground zero.

Solution: (*a*) Where the Mach effect commences, h and h_0 are the same, i. e., zero, so that in this case $d=d_0 \times W^{1/3}$. From Fig. 3.93, the cube root of 1,000 KT is 10, and from Fig. 3.94c, the Mach effect for a 1 KT air burst sets in at 0.13 mile from ground zero. Hence, for the 1 MT air burst the Mach effect will commence at a distance from ground zero given by

$$d=d_0 \times W^{1/3}=0.13 \times 10=1.3 \text{ miles. } \textit{Answer.}$$

(*b*) The distance d_0 for 1 KT corresponding to 2.75 miles for 1 MT is

$$d_0=\frac{d}{W^{1/3}}=\frac{2.75}{10}=0.275 \text{ mile.}$$

The height of the Mach stem at this distance from ground zero for a 1 KT air burst is found from Fig. 3.94c to be 37 feet. Hence, for the 1 MT typical air burst,

$$h=h_0 \times W^{1/3}=37 \times 10=370 \text{ feet. } \textit{Answer.}$$

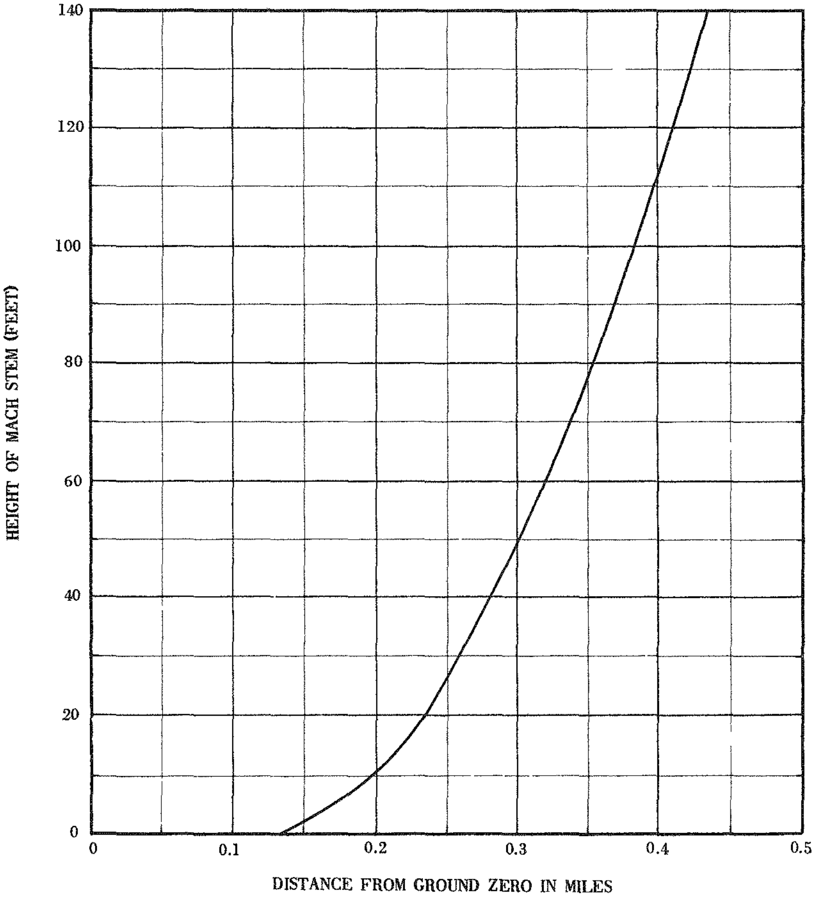


Figure 3.94c. Height of Mach stem (path of triple point) for a 1-kiloton air burst.

The curves show the variation of the horizontal component of the peak dynamic pressure with distance from ground zero for 1 KT air and surface bursts in a standard sea level atmosphere under average surface conditions.

Scaling. For yields other than 1 KT, the range in which a given dynamic pressure level extends scales as the cube root of the yield, i. e.,

$$d=d_0\times W^{1/3},$$

where, for a given peak dynamic pressure,

d_0 is the distance from ground zero for 1 KT,

and

d is the distance from ground zero for W KT.

Example

Given: A 1 MT surface burst.

Find: The horizontal component of the peak dynamic pressure to be expected at 1.8 miles from ground zero.

Solution: From Fig. 3.93, the cube root of 1,000 KT is 10.

$$d_0=\frac{d}{W^{1/3}}=\frac{1.8}{10}=0.18 \text{ mile for 1 KT.}$$

From Fig. 3.95 the horizontal component of the peak dynamic pressure at 0.18 mile from a 1 KT contact surface burst is 2.8 psi. Therefore, the horizontal component of the peak dynamic pressure at 1.8 miles from ground zero for a 1 MT contact surface burst is 2.8 psi. *Answer.*

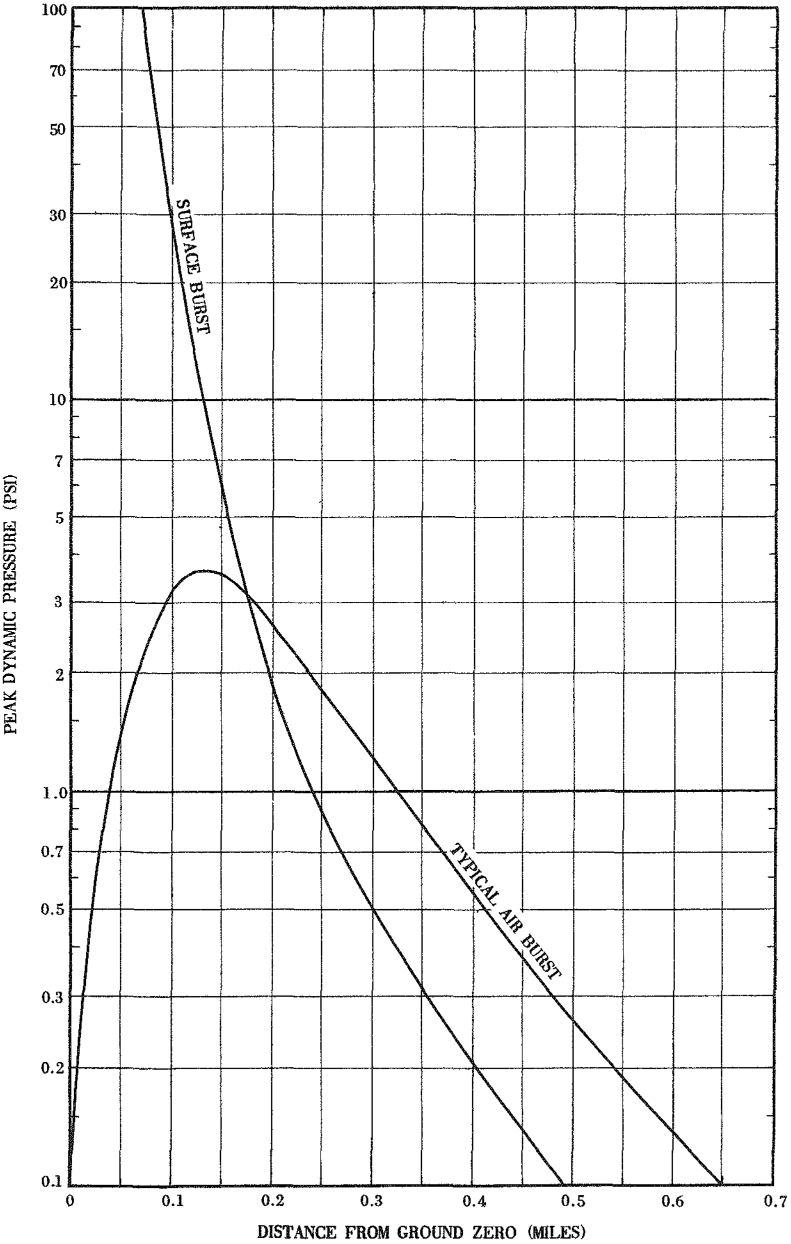


Figure 3.95. Horizontal component of peak dynamic pressure for a 1-kiloton explosion.

The curves show the dependence of the arrival time and the duration of the positive overpressure phase on distance from ground zero for 1 KT air and surface bursts in a standard sea level atmosphere under average surface conditions.

Scaling. For yields other than 1 KT, the duration and distance may be scaled in the following manner:

$$t=t_0\times W^{1/3} \text{ at } d=d_0\times W^{1/3},$$

where

t_0 is the arrival time and positive phase duration for 1 KT at a distance d_0,

and

t is the arrival time or positive phase duration for W KT at a distance d.

Example

Given: A 1 MT bomb is exploded on the surface.

Find: The time of arrival and duration of the positive phase at a distance of 5.5 miles.

Solution: From Fig. 3.93, the cube root of 1,000 KT is 10.

$$d_0=\frac{d}{W^{1/3}}=\frac{5.5}{10}=0.55 \text{ mile for 1 KT.}$$

From Fig. 3.96, the time of arrival at 0.55 mile for a 1 KT contact surface burst is 1.9 seconds and the duration is 0.44 second. For a 1 MT surface burst,

Arrival time: $t=t_0\times W^{1/3}=1.9\times 10=19$ seconds. *Answer.*

Duration: $t=t_0\times W^{1/3}=0.44\times 10=4.4$ seconds. *Answer.*

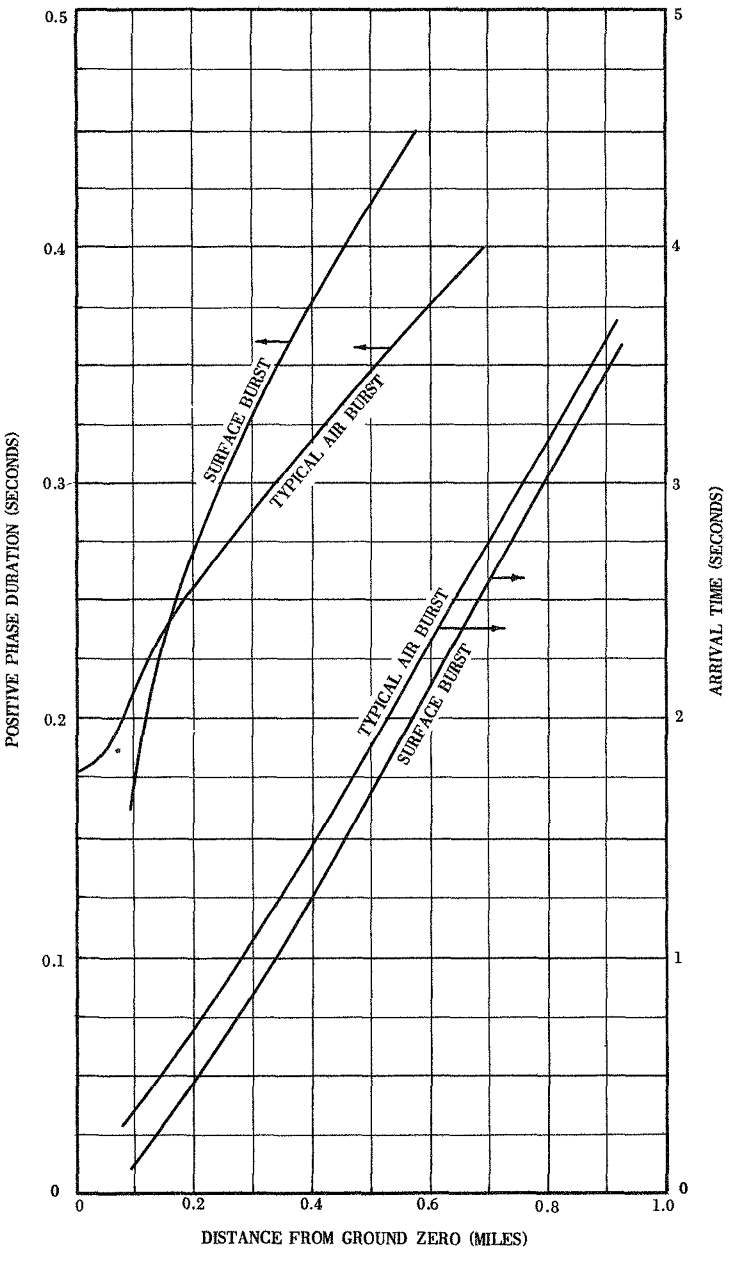


Figure 3.96. Times of arrival and positive phase durations at the surface for a 1-kiloton explosion.

The curves show the variation of overpressure and dynamic pressure (horizontal component) impulses in the positive phase with distance for 1 KT air and surface bursts in a standard sea level atmosphere under average surface conditions.

Scaling. For yields other than 1 KT, the impulse and distance may be scaled as follows:

$$I=I_0\times W^{1/3} \text{ at } d=d_0\times W^{1/3}$$

where

I_0 is the impulse for 1 KT at a distance d_0

and

I is the impulse for W KT at a distance d.

Example

Given: A 1 MT typical air burst.

Find: The distance at which the positive phase overpressure impulse is 5.5 lb-sec/in².

Solution: From Fig. 3.93, the cube root of 1,000 KT is 10.

$$I_0=\frac{I}{W^{1/3}}=\frac{5.5}{10}=0.55 \text{ lb-sec/in}^2.$$

From Fig. 3.97, the distance at which the positive phase overpressure impulse for a 1 KT typical air burst equals 0.55 lb-sec/in.² is 0.40 mile. For a 1 MT typical air burst,

$$d=d_0\times W^{1/3}=0.40\times 10=4.0 \text{ miles.} \quad \textit{Answer.}$$

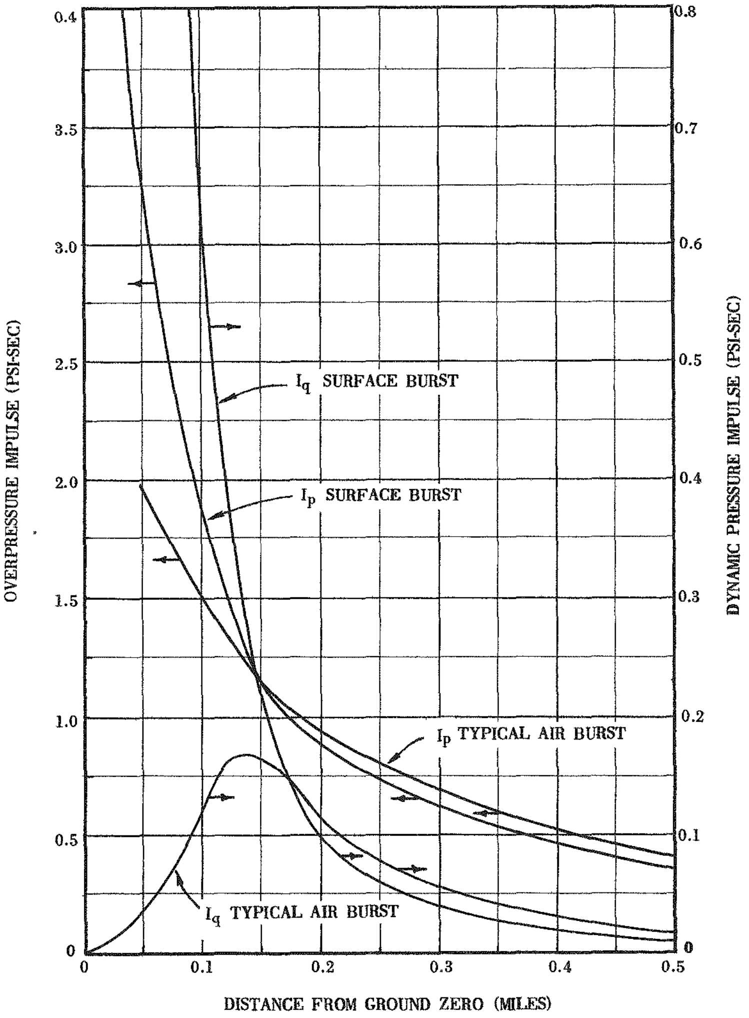


Figure 3.97. Overpressure and dynamic pressure positive phase impulse for a 1-kiloton explosion.

(Text continued from page 106.)

3.96 The dependence of the time of arrival of the shock front and the duration of the positive phase of the blast wave on the ground zero distance from a 1-kiloton contact surface burst and a typical air burst of the same energy are shown in Fig. 3.96.

3.97 Finally, Fig. 3.97 gives the overpressure positive phase and dynamic pressure impulses, I_p and I_q, respectively, as a function of distance from ground zero for a contact surface burst and a typical air burst of a 1-kiloton bomb. As in all the other cases, the results apply to an explosion in a standard sea level atmosphere under average surface conditions.

Figure 4.16 Wood-frame house after the nuclear explosion (1.7 psi over pressure)

Damage to interior doors varied; those which were open before the explosion suffered least. Window glass throughout the house was broken into fragments, and the force on the sash, especially in the front of the house, dislodged the frames.

4.18 Principal damage to the first floor system consisted of broken joists. Most breakages originated at knots in the lower edges of the 2 x 8 inch timbers (16-inch spacing). Most of the studs (2 x 4 inches with 16-inch spacing) at the front end of the house were cracked.

4.19 The second-story system suffered relatively little in structural respects, although windows were broken and plaster cracked. Damage to the roof consisted mainly of broken rafters (2 x 6 inches with 16-inch spacing). All but one of those at the front side were affected, but none of the rafters at the back was badly damaged. The roof (span 14 feet from front wall to ridge) was sprung slightly at the ridge.

4.20 The basement showed no signs of damage except to the windows, and the entry door and frame. The shelters in the basement were intact.

Figure 4 22 Strengthened wood frame house after a nuclear explosion (4 psi overpressure)

TWO-STORY WOOD-FRAME HOUSE: 1955 TEST

4.21 Based upon the results described above, certain improvements in design were incorporated in two similar wood-frame houses used in the 1955 test. The following changes, which increased the estimated cost of the houses some 10 percent above that for normal construction, were made: (1) improved connection between exterior walls and foundations; (2) reinforced-concrete shear walls to replace the pipe columns in the basement; (3) increase in size and strengthening of connections of first-floor joists; (4) substitution of plywood for lath and plaster; (5) increase in size of rafters (to 2 x 8 inches) and wall studs; and (6) stronger nailing of window frames in wall openings.

4.22 Even with these improvements, it was expected that almost complete destruction would occur at 5 pounds per square inch peak overpressure, and so one of the houses was located where the overpressure at the Mach front would be 4 pounds per square inch. Partly because of the increased strength and partly because of the lower air blast pressure the house did not collapse (Fig. 4.22). However, the superstructure was so badly damaged that it could not have been occupied without expensive repair which would not have been economically advisable.

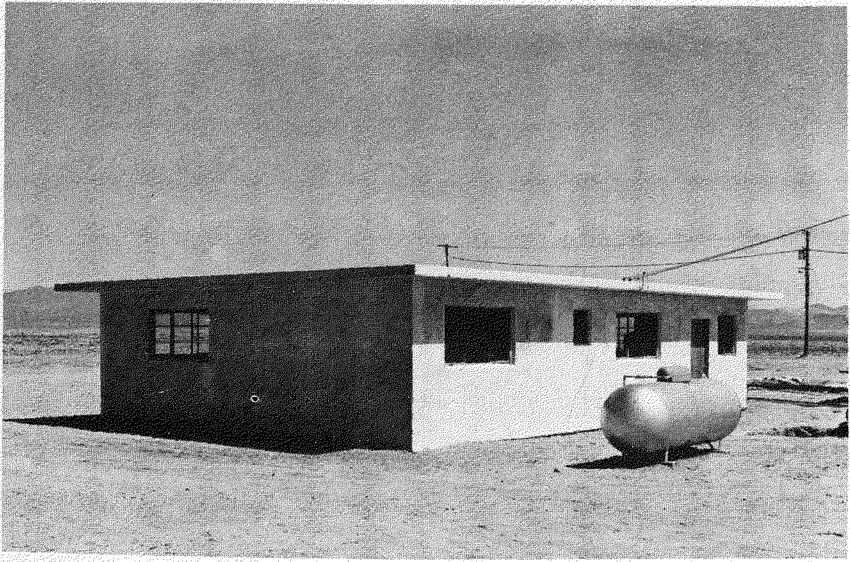


Figure 4.37. Reinforced precast concrete house before a nuclear explosion, Nevada Test Site.

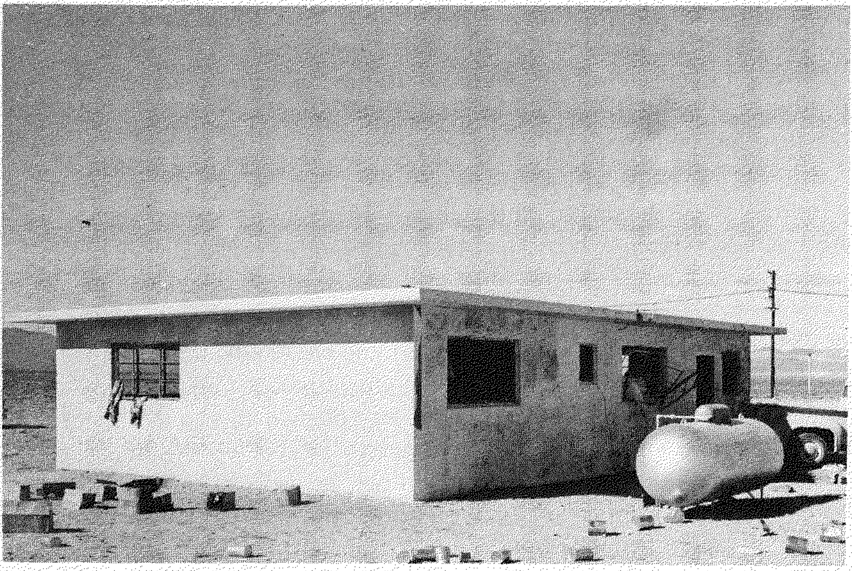


Figure 4.38. Reinforced precast concrete house after the nuclear explosion (5 psi overpressure). The LP-gas tank, sheltered by the house, is essentially undamaged.

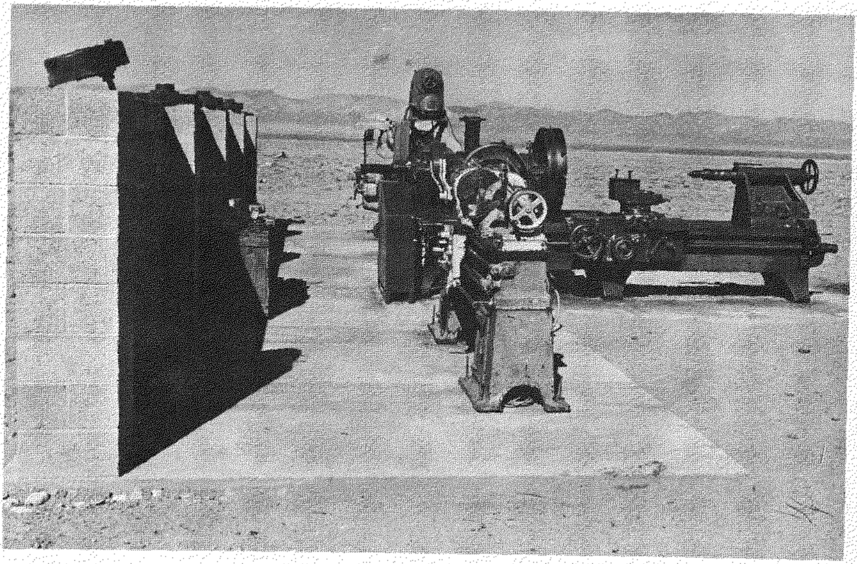


Figure 4.75. Machine tools behind masonry wall before a nuclear explosion, Nevada Test Site.

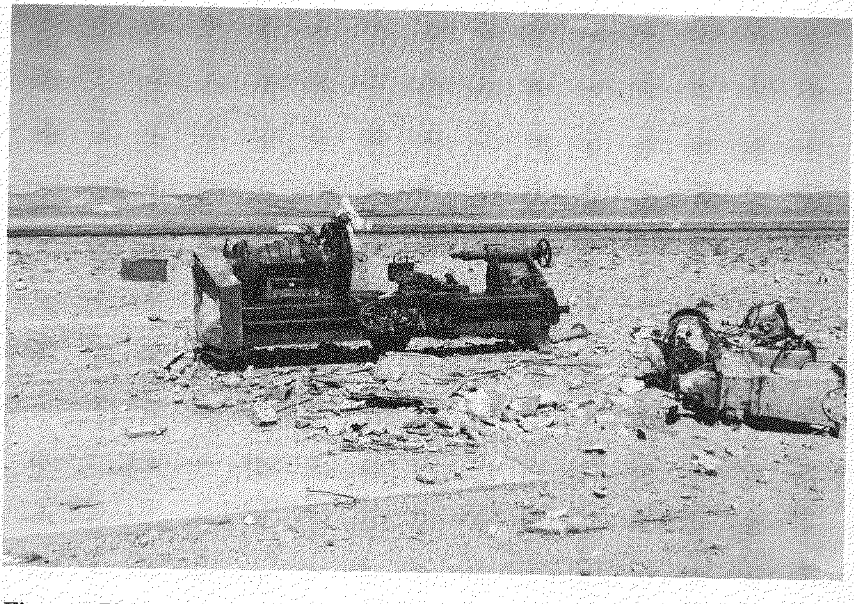


Figure 4.76a. Machine tools after the nuclear explosion (10 psi overpressure).

Figure 4.76b Heavy-duty lathe after the nuclear explosion (10 psi over pressure)

unprotected, suffered especially severely Gears and gear cases were damaged, hand valves and control levers were broken off, and drive belts were broken. It appears, however, that most of the missile damage could be easily repaired, if replacement parts were available, since major dismantling would not be required.

4.78 Behind the two-story brick house in the overpressure region of 5 pounds per square inch (§4.30) was erected a 200-ton capacity hydraulic press weighing some 49,000 pounds. The location was chosen as being the best to simulate actual factory conditions. This unusually tall (19 feet high) and slim piece of equipment showed little evidence of blast damage, even though the brick house was demolished. It is probable that the house provided some shielding from the blast wave Further, at the existing blast pressure, missiles did not have high velocities Such minor damage as was suffered by the machine was probably due to falling debris from the house

4.79 At the 3-pounds per square inch overpressure location, there were two light, industrial buildings of standard type, described earlier. In each of these was placed a vertical milling machine weighing about 3,000 pounds, a 50-gallon capacity, stainless steel, pressure vessel weighing roughly 4,100 pounds, and a steel steam oven, approximately

Figure 4.82a. *Upper photo:* Reinforced-concrete, aseismic structure; window fire shutters were blown in by blast and the interior gutted by fire (0.12 mile from ground zero at Hiroshima). *Lower photo:* Burned out interior of similar structure.

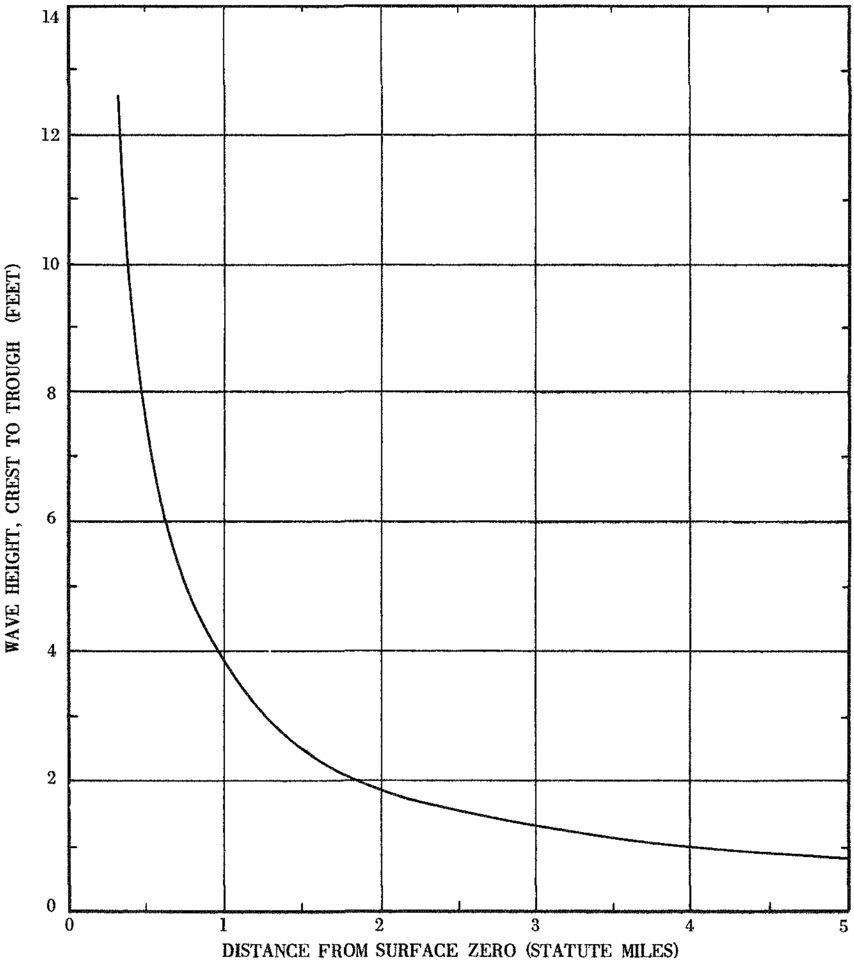


Figure 5.54. Maximum wave height (crest to trough) for a 1-kiloton explosion in water 85 feet deep.

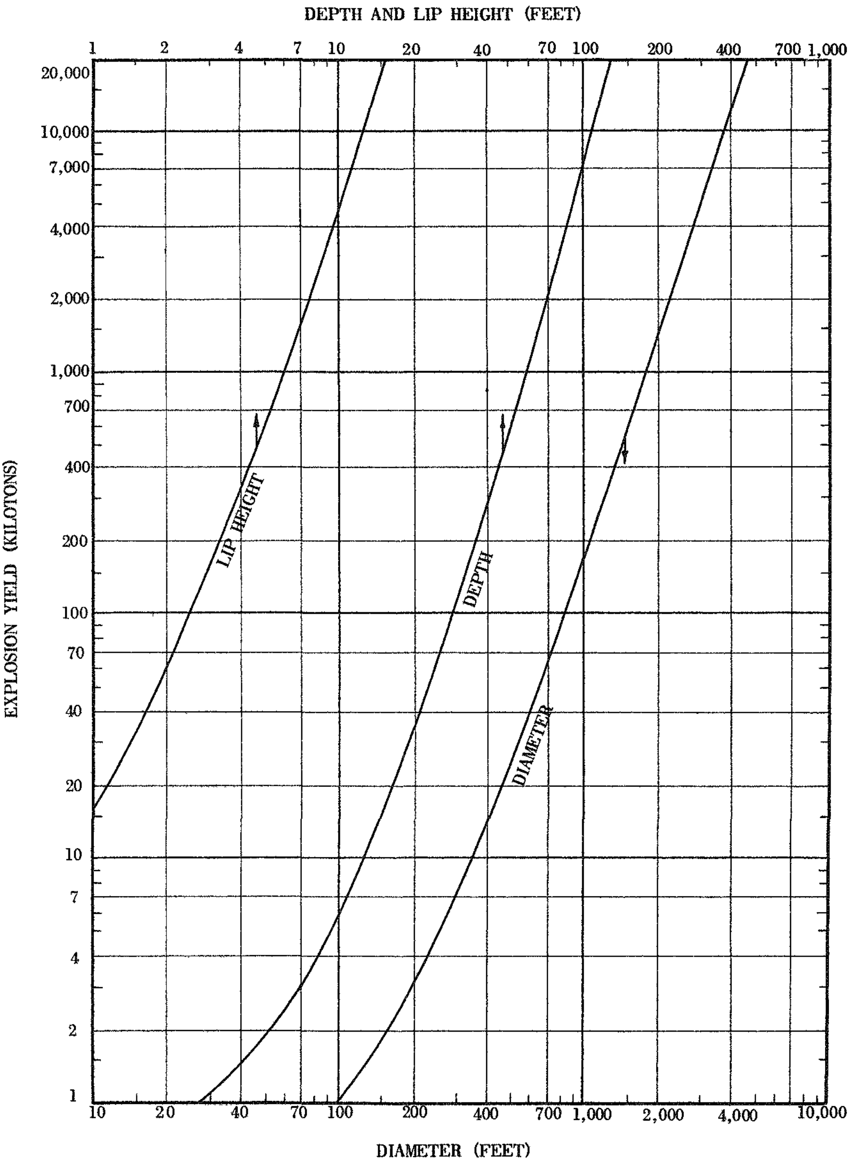


Figure 5.55. Dimensions of crater from underwater burst.

and orientation with respect to the incident blast wave. The damage-distance relationships for these structural types are summarized in Fig. 6.41a.

TABLE 6.12

DAMAGE CRITERIA FOR SHALLOW BURIED OR EARTH COVERED SURFACE STRUCTURES

Type of structure	Damage class	Peak overpressure (psi)	Nature of damage
Light, corrugated steel arch, surface structure (10-gage corrugated steel with a span of 20 to 25 feet) with 3 feet of earth cover over the crown.	A	35–40	Complete collapse.
	B	30–35	Collapse of portion of arch facing blast.
	C	20–25	Deformation of end walls and arch, possible entrance door damage.
	D	10–15	Possible damage to ventilation system and entrance door.
Light, reinforced-concrete surface or underground shelter with 3 feet minimum earth cover. (Panels 2 to 3 inches thick, with beams spaced on 4-foot centers.)	A	30–35	Collapse.
	B	25–30	Partial collapse.
	C	15–25	Deformation, severe cracking and spalling of panels.
	D	10–15	Cracking of panels, possible entrance door damage.

6.13 An illustration of B-type damage to a 10-gage corrugated steel-arch, earth-covered, surface structure is shown in Fig. 6.13. It will be noted that about half of the arch has collapsed. This failure was attributed primarily to the dynamic pressure acting on the forward slope of the earth mound.

6.14 The peak overpressure for the complete collapse of the corrugated steel-arch structure, with 3 feet of earth cover, is given in Table 6.12 as 35 to 40 pounds per square inch. However, it has been estimated that if this structure had been completely buried, so that no earth mound was required, an overpressure of 40 to 50 pounds per square inch would have been necessary to cause it to collapse. This increase in the required overpressure is due to the fact that the dynamic pressure is minimized under these conditions. It may be mentioned

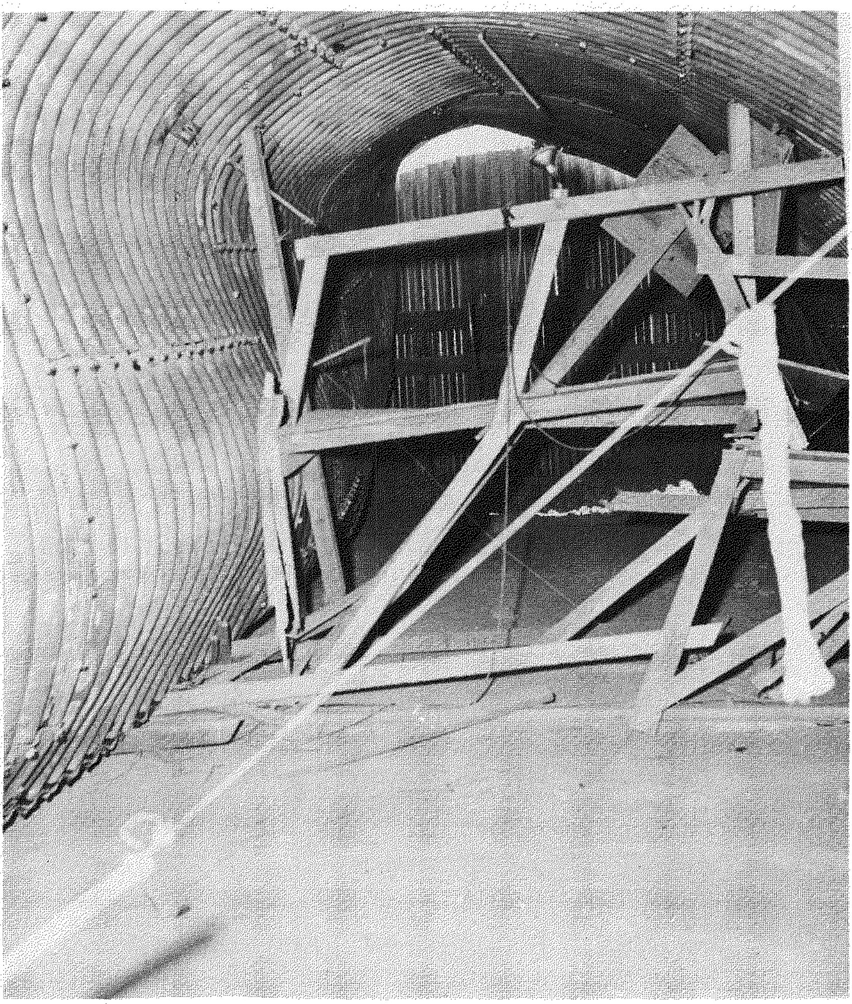


Figure 6.13. B-type damage to earth-covered 10-gage corrugated steel structure.

that, using standard engineering techniques, it is possible to design underground structures which will withstand blast overpressures in excess of 100 pounds per square inch at the surface (see Chapter XII).

DAMAGE TO LAND TRANSPORTATION EQUIPMENT

6.15 The general types of land transportation equipment considered here include civilian motor-driven vehicles (cars, trucks) and

Figure 6.24b. Forest stand after a nuclear explosion, C damage (2.4 psi overpressure).

TABLE 6.24

DAMAGE CRITERIA FOR FORESTS

Damage class	Nature of damage	Equivalent hurricane wind velocity (miles per hour)
A & B	Up to 90 percent of trees blown down; remainder denuded of branches and leaves (Fig. 6.24a). (Area impassable to vehicles and very difficult on foot.)	130–140
C	About 30 percent of trees blown down; remainder have some branches and leaves blown off (Fig. 6 24b). (Area passable to vehicles only after extensive clearing.)	90–100
D	Very few trees blown down, some leaves and branches blown off. (Area passable to vehicles.)	60–80

From the nomogram and bar chart in Fig. 6.41a the nature of the damage to various diffraction-sensitive structures can be determined at any given distance from ground zero for an explosion of specified energy yield. The symbols A, B, C, and D in the bars refer to degrees of damage of decreasing severity, as described in the text. The abbreviations "SB" and "AB" at the head of each set of bars indicates a surface burst and an air burst, respectively.

Scaling. The chart can be used directly for energy yields in the range from 1 KT to 20 MT. For yields W MT, in excess of 20 MT, the scaling law is

$$d = \frac{W^{1/3}}{2.71} d_0 \text{ for } W > 20 \text{ MT},$$

where

d = distance from ground zero for a W MT ($>$20 MT) explosion to cause a specific damage,

and

d_0 = distance from ground zero for a 20 MT explosion to cause the same damage.

Example

Given: A 1 MT air burst.

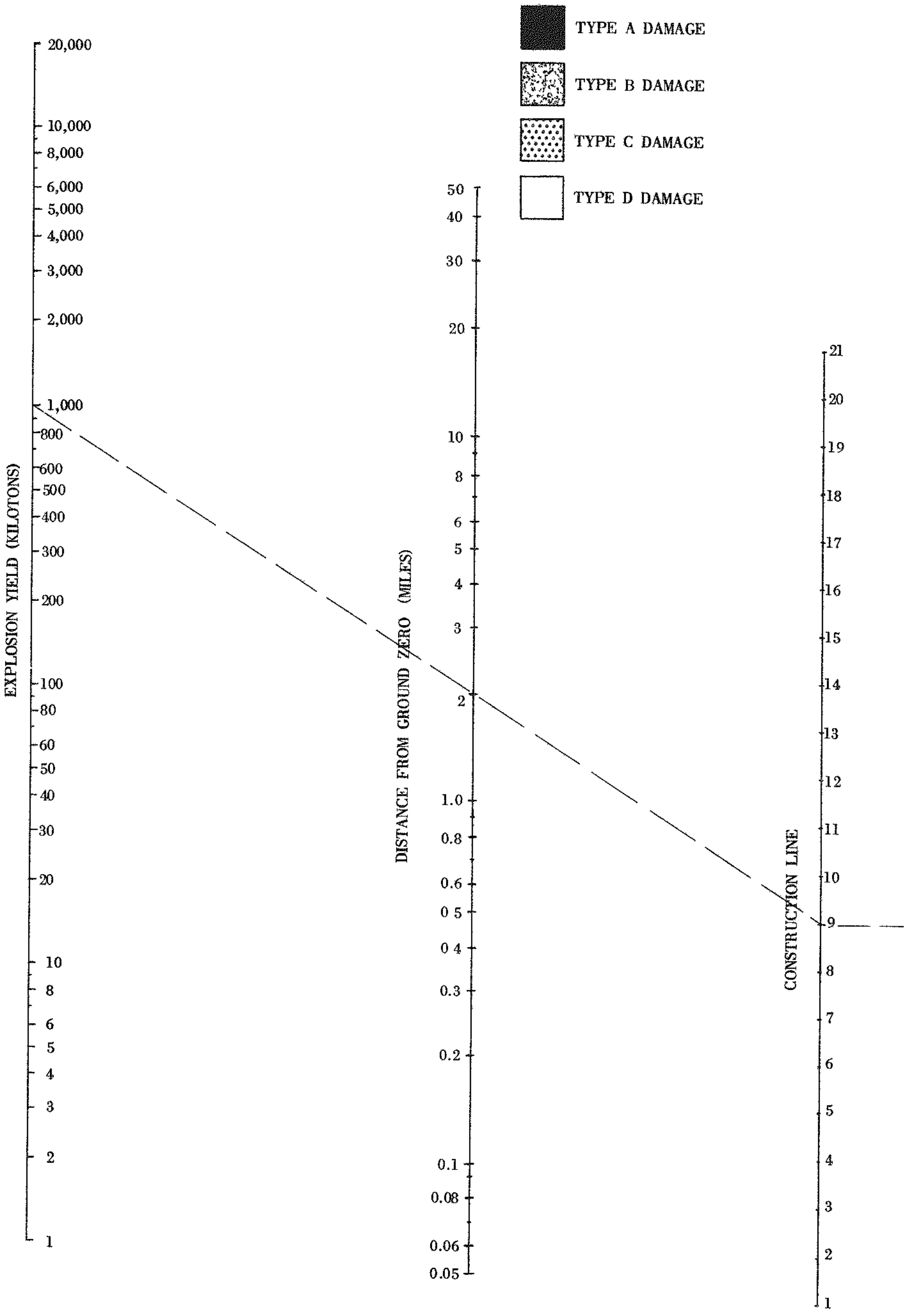
Find: The nature of the damage suffered by (*a*) a blast-resistant, reinforced-concrete structure, (*b*) a conventional reinforced-concrete structure, and (*c*) a wood-frame house, at 2 miles from ground zero.

Solution: Find the point indicating 1 megaton on the left scale of the nomogram and the one representing 2 miles on the center scale; draw a straight line through these points until it cuts the line at the right ("construction line"). From the point of intersection draw a horizontal line through the bars showing degrees of damage.

(*a*) A blast-resistant, reinforced-concrete building will suffer essentially no structural damage.

(*b*) A conventional reinforced-concrete structure will suffer B damage.

(*c*) A wood-frame house will suffer A damage, i. e., essentially complete destruction. *Answer.*


TYPE A DAMAGE
TYPE B DAMAGE
TYPE C DAMAGE
TYPE D DAMAGE
EXPLOSION YIELD (KILOTONS)
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
DISTANCE FROM GROUND ZERO (MILES)
50
40
30
20
10
8
6
5
4
3
2
1.0
0.8
0.6
0 5
0 4
0.3
0.2
0.1
0.08
0.06
0.05
CONSTRUCTION LINE
21
20
19
18
17
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12
11
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6
5
4
3
2
1

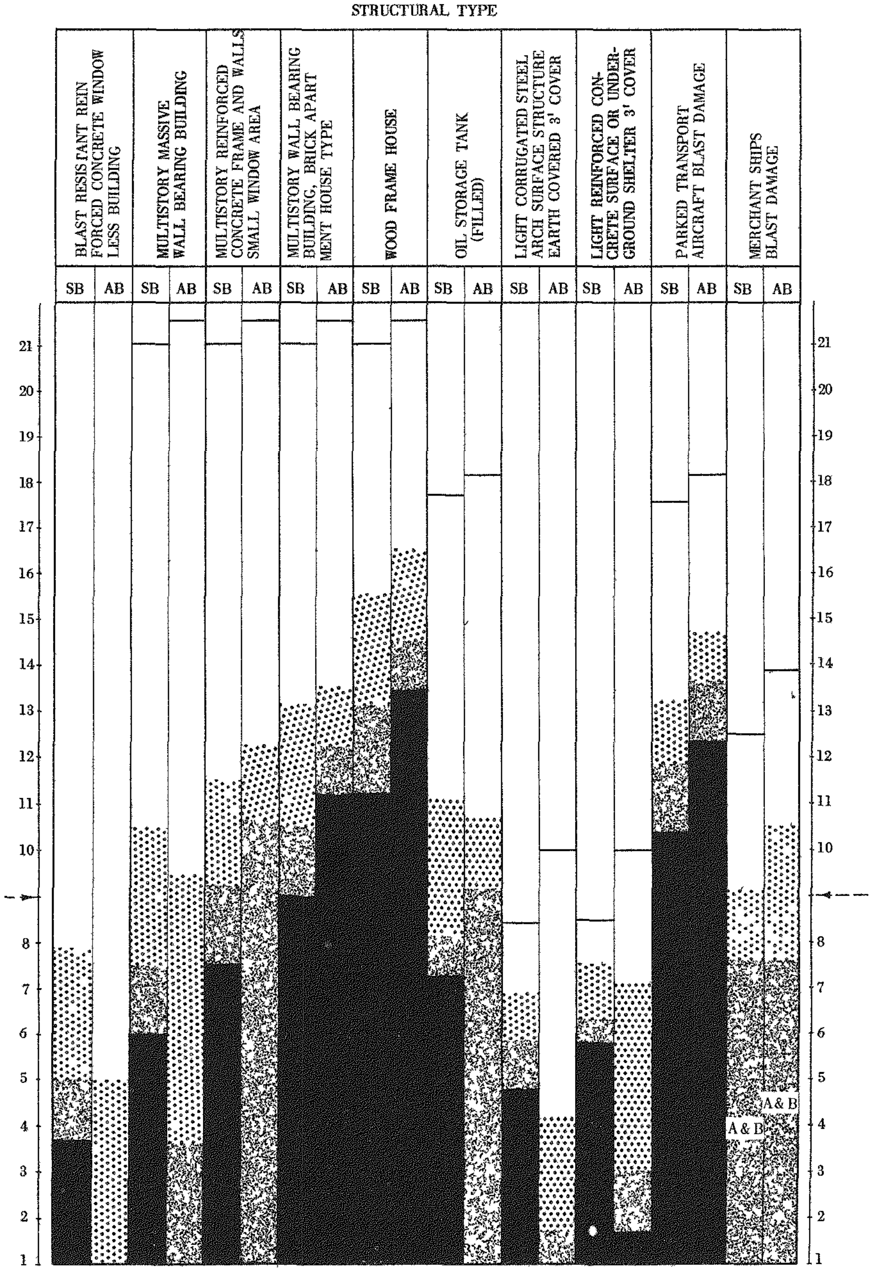

Figure 6.41a. Damage-distance relationships for diffraction-type structure.

(Text continued from page 246.)

cube root law may be used for both diffraction and drag type targets, provided the reference explosion is taken as 20 megatons. Thus, if *d* is the distance from ground zero for an explosion of *W* (which is greater than 20) megatons, where a certain degree of damage is expected, and d_0 is the distance for the same damage for a 20-megaton explosion, then

$$\frac{d}{d_0}=\left(\frac{W}{20}\right)^{1/3} \text{ or } d=\frac{W^{1/3}}{2.71}\,d_0.$$

Since d_0 can be obtained from the charts, the value of *d* for an explosion yield of *W* (which is in excess of 20) megatons can be readily evaluated.

6.45 In conclusion, it should be mentioned that the damage charts do not take into consideration the possibility of fire. Generally speaking, except for fabric surfaces of aircraft, for which data are included, the direct effects of thermal radiation on structures and other targets under consideration are inconsequential. However, thermal radiation may initiate fires, and in structures with A, B, or C damage fires may start because of disrupted gas and electric utilities. In some cases, as in Hiroshima (§ 7.100), the individual fires may develop into a fire storm which may exist throughout a city, even beyond the range of significant blast damage. The spread of such a fire depends to a great extent on local weather (and other) conditions and is therefore difficult to predict. This limitation must be kept in mind when Figs. 6.41a, b, and c are used to make a damage analysis of a particular city or target area.

INTERACTION OF OBJECTS WITH AIR BLAST[2]

Development of Blast Loading

6.46 Because precise information concerning the effects of blast from nuclear explosions on structures is somewhat limited, the usual procedure for predicting blast damage is by an analysis, supported by such laboratory and full-scale empirical data as may be available. The first stage in this analysis is the determination of the air blast loading on the particular structure, followed by an evaluation of the response to this loading. Since actual structures are generally complex, the treatment presented here will refer to a number of idealized targets of simple shape.

(Text continued on page 256.)

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[2] The remaining sections of this chapter may be omitted without loss of continuity.

From the nomograms and bar charts in Fig. 6.41b and c the nature of the damage to various drag-sensitive structures can be determined at any given distance from ground zero for an explosion of specified energy yield. The symbols A, B, C, and D in the bars refer to degrees of damage of decreasing severity, as described in the text. The abbreviations "SB" and "AB" at the head of each set of bars indicate a surface burst and an air burst, respectively.

Scaling. For energy yields above 20 MT, the same cube root scaling law may be applied as that given on the page preceding Fig. 6.41a, for diffraction-sensitive structures.

Example

Given: A 1 MT air burst.

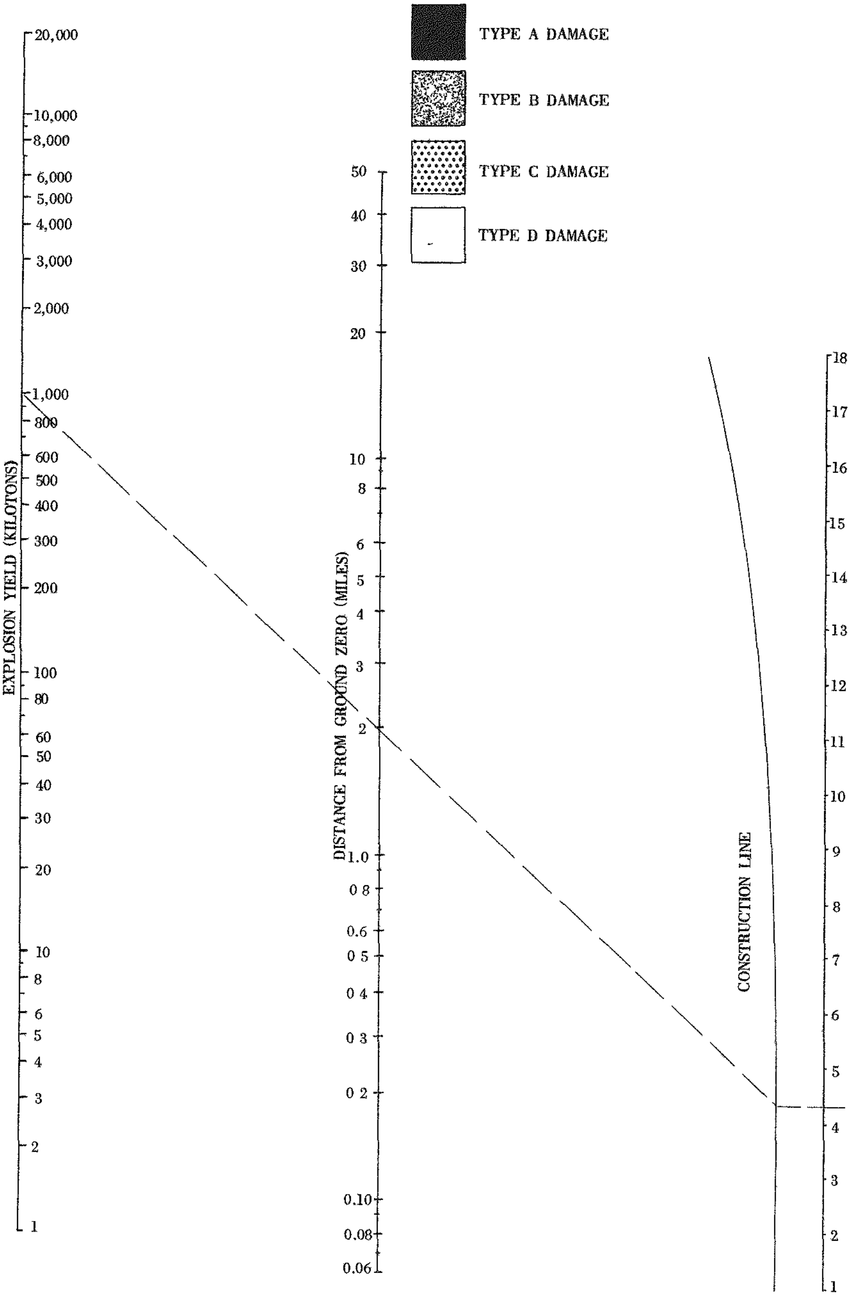
Find: The nature of the damage suffered by (*a*) a truss bridge, (*b*) a steel-frame industrial-type structure of medium strength, and (*c*) public utility (above ground power and telephone) lines, at 2 miles from ground zero.

Solution: Find the point indicating 1 megaton on the left scale of the nomogram and the one representing 2 miles on the center scale; draw a straight line through these points until it cuts the line at the right ("construction line"). From the point of intersection draw a horizontal line through the bars showing degrees of damage.

(*a*) A truss bridge, more or less irrespective of its length, will suffer C damage.

(*b*) A medium strength, steel-frame industrial building will suffer A damage from an air burst.

(*c*) Public utility (above ground power and telephone) lines will suffer A damage, irrespective of whether they are oriented radially or transversely to the direction of the blast wave. *Answer.*


TYPE A DAMAGE
TYPE B DAMAGE
TYPE C DAMAGE
TYPE D DAMAGE
EXPLOSION YIELD (KILOTONS)
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
DISTANCE FROM GROUND ZERO (MILES)
50
40
30
20
10
8
6
5
4
3
2
1.0
0 8
0.6
0 5
0 4
0 3
0 2
0.10
0.08
0.06
CONSTRUCTION LINE
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

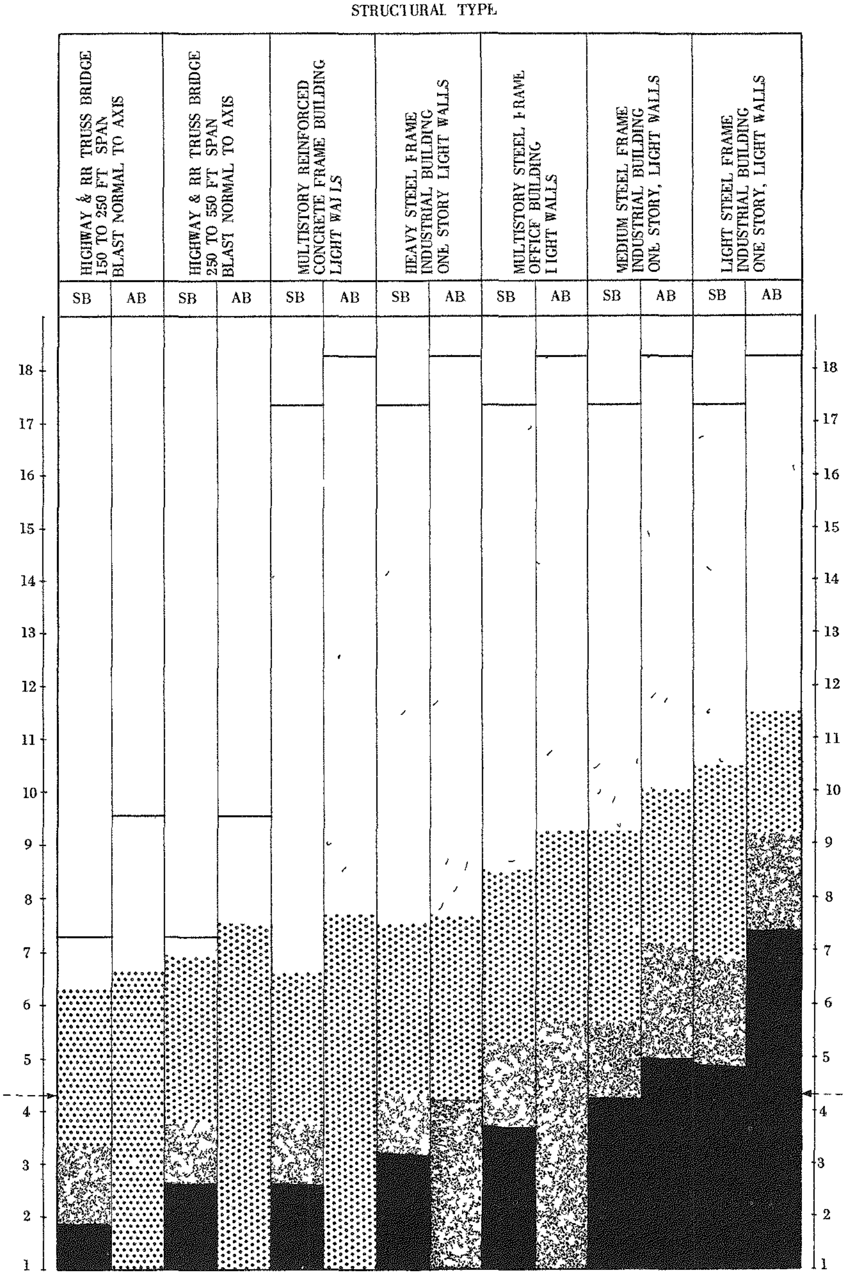
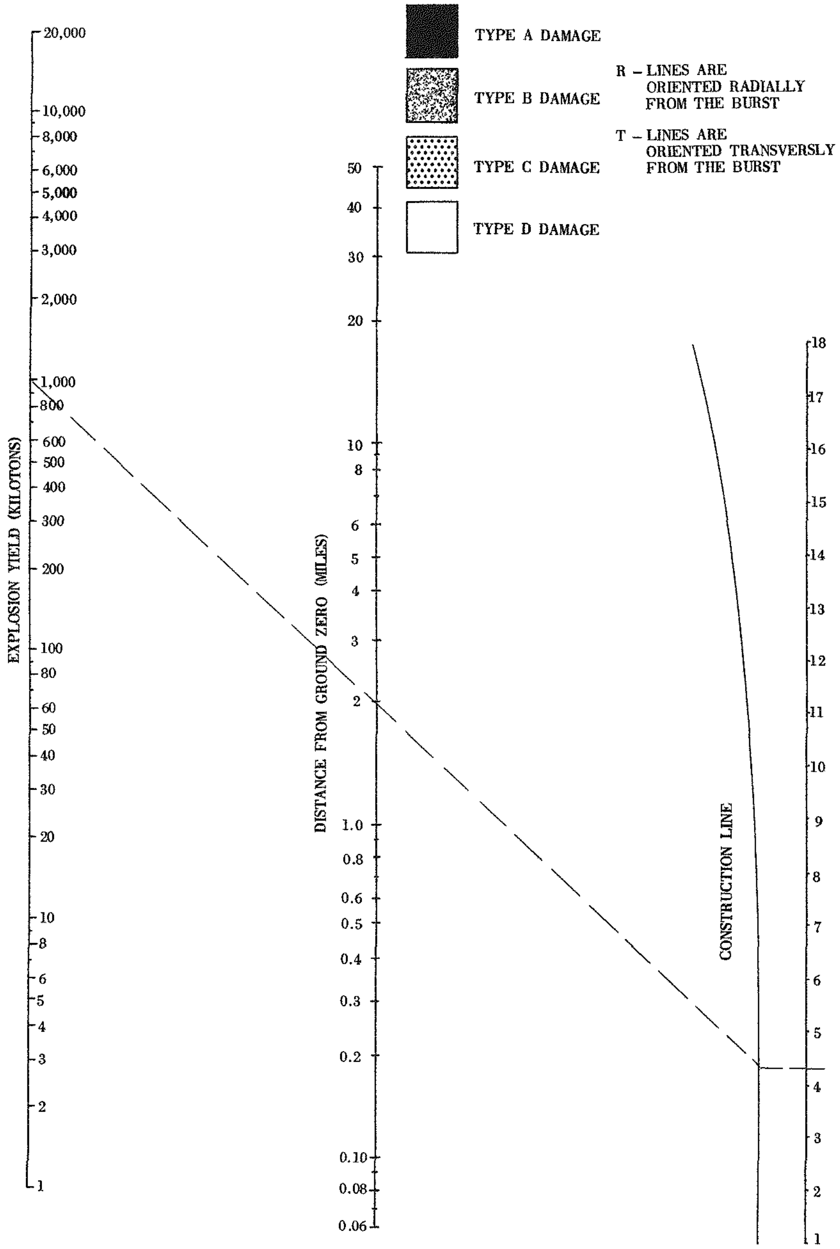


Figure 6.41b. Damage-distance relationships for drag-type structures (buildings).


TYPE A DAMAGE
TYPE B DAMAGE
TYPE C DAMAGE
TYPE D DAMAGE
R – LINES ARE ORIENTED RADIALLY FROM THE BURST
T – LINES ARE ORIENTED TRANSVERSLY FROM THE BURST
EXPLOSION YIELD (KILOTONS)
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
DISTANCE FROM GROUND ZERO (MILES)
50
40
30
20
10
8
6
5
4
3
2
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.10
0.08
0.06
CONSTRUCTION LINE
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

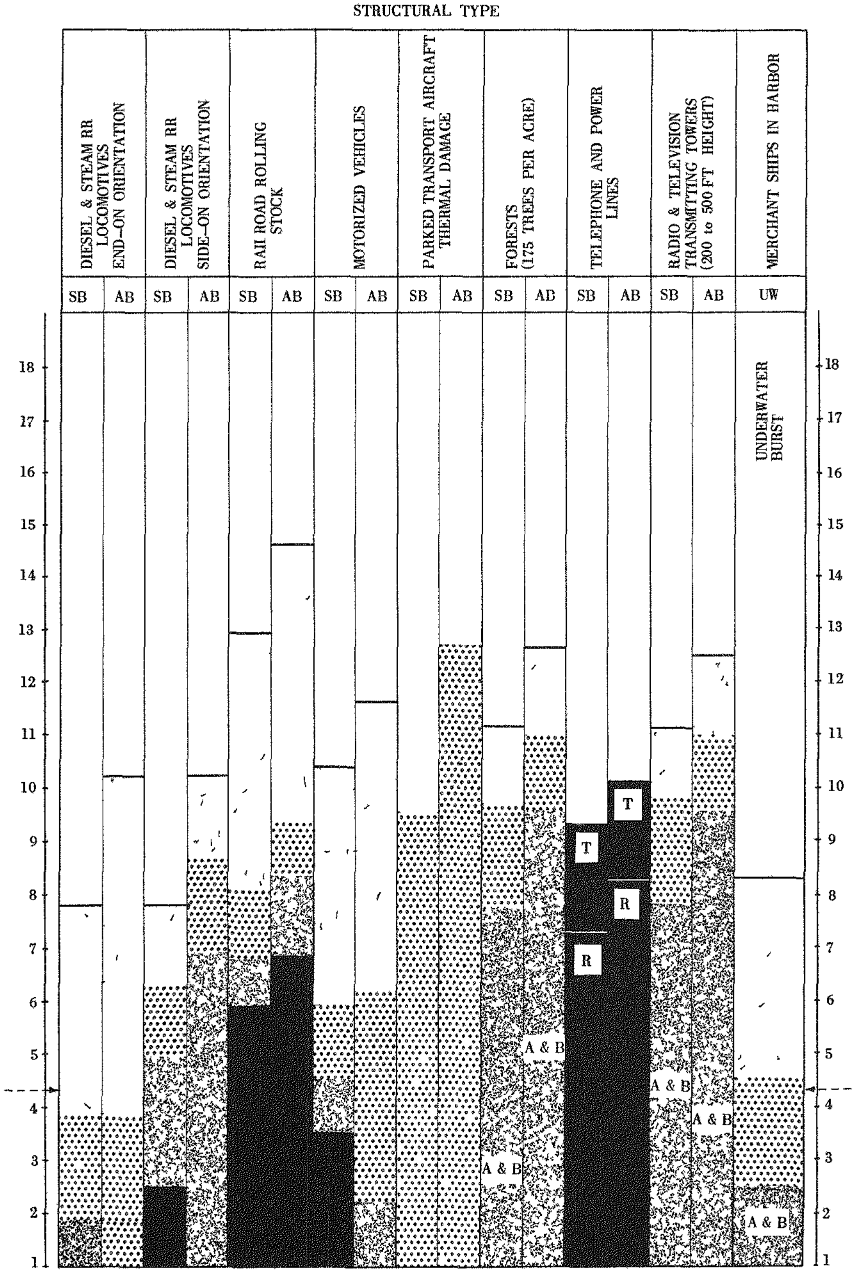


Figure 6.41c. Damage-distance relationships for drag-type structures (other than buildings).

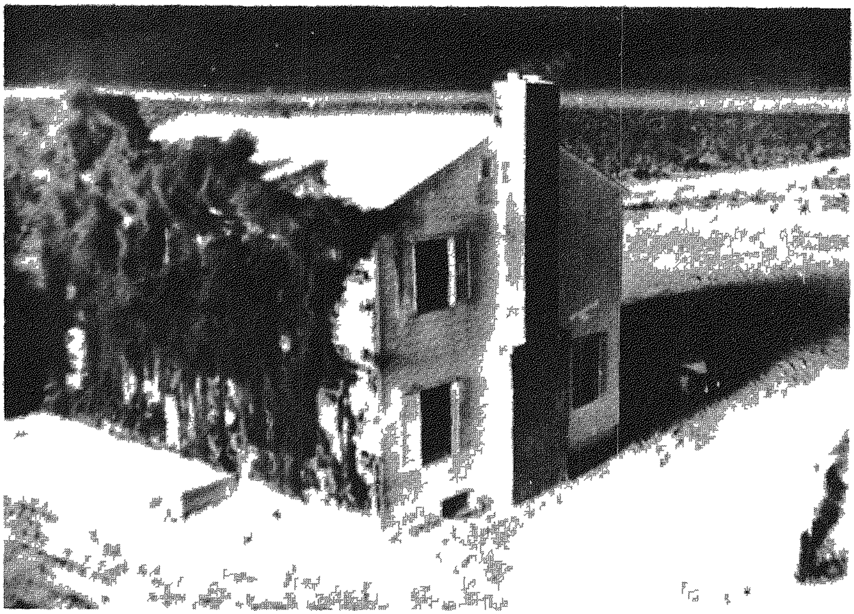


Figure 7 34a Thermal effects on wood frame house almost immediately after explosion (about 25 cal/sq cm)

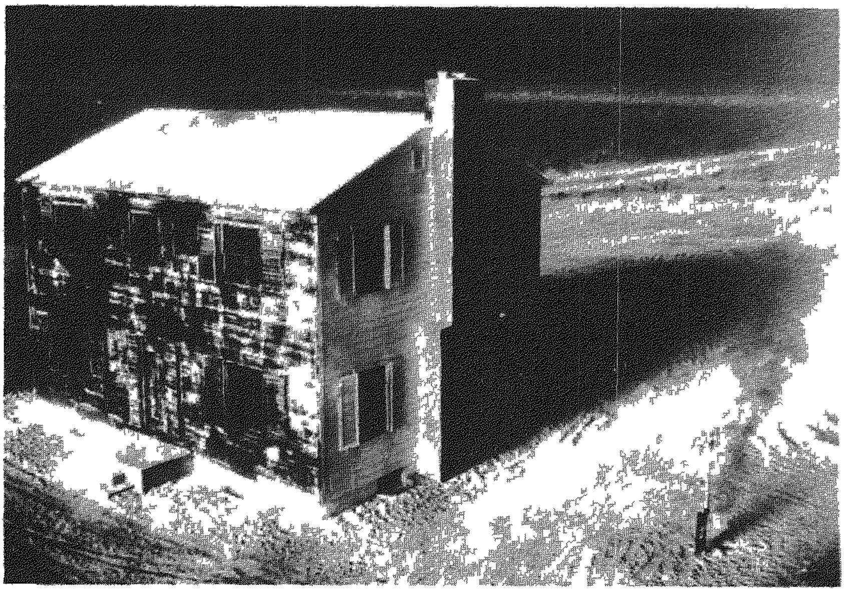


Figure 7 34b Thermal effects on wood frame house 2 seconds later

TABLE 7.61

APPROXIMATE THERMAL ENERGIES FOR IGNITION OF FABRICS

Material	Weight (oz/sq yd)	Ignition energy (cal/sq cm)	
		20 kilotons	10 megatons
Rayon-acetate taffeta (wine)	3	2	3
Cotton chenille bedspread (light blue)	—	4	8
Doped fabric, aluminized cellulose acetate	—	18	35
Cotton muslin, oiled window shade (green)	8	5	11
Cotton awning canvas (green)	12	5	9
Cotton corduroy (brown)	8	6	11
Rayon twill lining (black)	3	1	2
Cotton venetian blind tape, dirty (white)	—	7	12
Cotton sheeting, unbleached, washed (cream)	3	15	30
Rayon twill lining (beige)	3	8	16
Rayon gabardine (black)	6	3	6
Cotton shirting (tan)	5	7	13
Cotton denim, used (blue)	10	8	13
Cotton and rayon auto seat cover (dark blue)	9	8	13
Acetate shantung (black)	3	9	15
Rayon-acetate drapery (wine)	5	9	16
Rayon marquisette curtain (ivory)	2	9	14
Cotton denim, new, washed (blue)	10	9	14
Cotton auto seat upholstery (green, brown, white)	10	9	16
Rayon gabardine (gold)	7	9	20
Cotton venetian blind strap (white)	—	16	30
Wool flannel, new, washed (black)	7	8	16
Cotton tapestry, tight weave (brown shades)	12	16	30
Wool surface, cotton base, auto seat upholstery (gray)	13	*16	*35
Wool, broadloom rug (gray)	7	*16	*35
Wool pile chair upholstery (wine)	16	*16	*35
Wool pile frieze chair upholstery (light brown)	14	*16	*35
Nylon hosiery (tan)	—	*5	*10
Cotton mattress stuffing (gray)	—	8	16
Burlap, heavy, woven (brown)	18	8	16
Rubberized canvas auto top (gray)	20	*16	*28

*In these cases the material was not ignited to sustained burning by the incident thermal energy indicated.

TABLE 7.65

THERMAL ENERGIES FOR IGNITION OF HOUSEHOLD MATERIALS

Material	Weight (oz/sq yd)	Ignition energy (cal/sq cm)	
		20 kilotons	10 megatons
Dust mop (oily gray)	—	3	5
Newspaper, shredded	2	2	4
Paper, crepe (green)	1	4	8
Newspaper, single sheet	2	3	6
Newspapers piled flat, surface exposed	—	3	6
Newspapers, weathered, crumpled	1	3	6
Newspaper, crumpled	2	4	8
Cotton waste (oily gray)	—	5	8
Paper, bond typing, new (white)	2	15	30
Paper, Kraft, single sheet (tan)	2	7	14
Matches, paper book, blue heads exposed	—	5	9
Cotton string scrubbing mop, used (gray)	—	6	10
Cellulose sponge, new (pink)	39	6	10
Cotton string mop, weathered (cream)	—	7	13
Paper bristol board, 3 ply (dark)	10	8	15
Paper bristol board, 3 ply (white)	10	12	25
Kraft paper carton, flat side, used (brown)	16	8	15
Kraft paper carton, corrugated edges exposed, used (brown)	—	12	25
Straw broom (yellow)	—	8	17
Excelsior, Ponderosa pine (light yellow)	2 lb/cu ft	5	12
Tampico fiber scrub brush, used (dirty yellow)	—	10	20
Palmetto fiber scrub brush, used (rust)	—	12	25
Twisted paper, auto seat cover, used (multicolor)	13	12	25
Leather, thin (brown)	6	*15	*30
Vinyl plastic auto seat cover	10	*16	*27
Woven straw, old (yellow)	13	*16	*33

*Indicates material was not ignited to sustained burning by the incident thermal energy indicated.

ignition to occur, under average conditions, may be estimated from the results in Table 7.65 to be about 5 calories per square centimeter. Entering Fig. 7.67 at the point on the vertical axis corresponding to 1,000 kilotons, the horizontal line is followed across until it intersects the

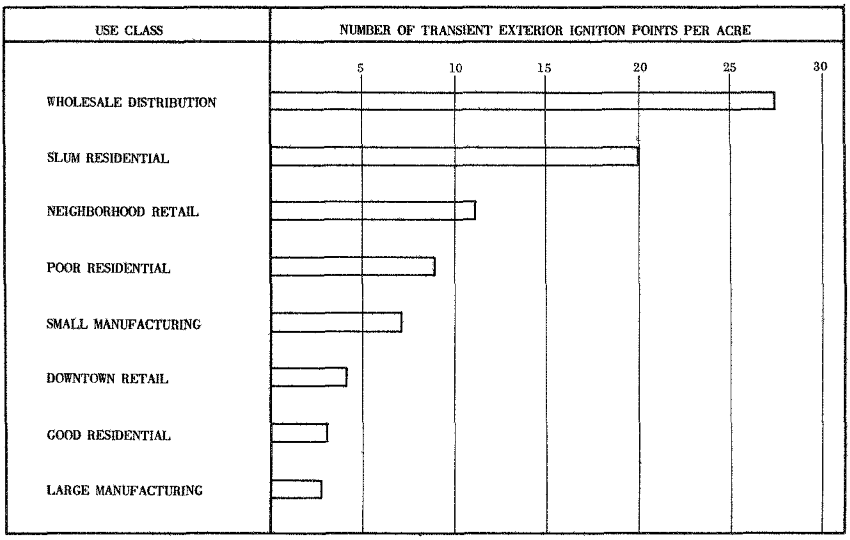


Figure 7.80. Frequency of exterior ignition points for various areas in a city.

number of large cities in the United States. It is seen that the density of ignition points is greatest in wholesale distribution and slum residential areas, and is least in good residential and large manufacturing areas.[5] Paper was the commonest ignitable material found everywhere except in downtown retail areas where awnings represented the major source of fire.

7.81 The density of ignition points provides some indication of the chance of fires being started under ideal weather conditions. But the results in Fig. 7.80 are by themselves not sufficient to permit an estimate to be made of the number of significant fires that will actually result. In the first place, at locations closer to ground zero, where the thermal energy exceeds about 12 calories per square centimeter, almost all the ignitable materials will actually flame (Table 7.65). On the other hand, at greater distances, only those most easily ignitable will catch fire. Further, the formation of a significant fire, capable of spreading, will require appreciable quantities of combustible material close by, and this may not always be available.

7.82 The fact that accumulations of ignitable trash close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses, each having a yard enclosed with a wooden

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[5] The area types are in accordance with the classification used by the U. S. Bureau of Census.

fence, were exposed to 12 calories per square centimeter of thermal radiation. One house, at the left of Fig. 7.82, had weathered siding showing considerable decay, but the yard was free from trash. The next house also had a clean yard and, further, the exterior siding was well maintained and painted. In the third house, at the right of the photograph, the siding, which was poorly maintained, was weathered, and the yard was littered with trash.

7.83. The state of the three houses after the explosion is seen in Fig. 7.83. The third house, at the right, soon burst into flame and was burned to the ground. The first house, on the left, did ignite but it did not burst into flame for 15 minutes. The well maintained house in the center with the clean yard suffered scorching only. It is of interest to recall that the wood of a newly erected white-painted house exposed to about 25 calories per square centimeter was badly charred but did not ignite (Fig. 7.34b).

7.84 The value of fire-resistive furnishing in decreasing the number of ignition points was also demonstrated in the 1953 tests. Two identical, sturdily constructed houses, each having a window 4 feet by 6 feet facing the point of burst, were erected where the thermal radiation exposure was 17 calories per square centimeter. One of the houses contained rayon drapery, cotton rugs, and clothing, and, as was expected, it burst into flame immediately after the explosion and burned completely. In the other house, the draperies were of vinyl plastic, and rugs and clothing were made of wool. Although more ignition occurred, the recovery party, entering an hour after the explosion, was able to extinguish fires.

7.85 There is another point in connection with the initiation of fires by thermal radiation that needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan (§ 7.92), but this may have been an exceptional case. The matter has been studied, both in connection with the effects in Japan and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires (see § 7.93).

SPREAD OF FIRES

7.86 The spread of fires in a city, depends upon a variety of conditions, e. g., weather, terrain, and closeness and combustibility of the buildings. A detailed review of large-scale fires has shown, however, that if other circumstances are more-or-less the same, the most

Figure 7.82 Wooden test houses before exposure to a nuclear explosion, Nevada Test Site

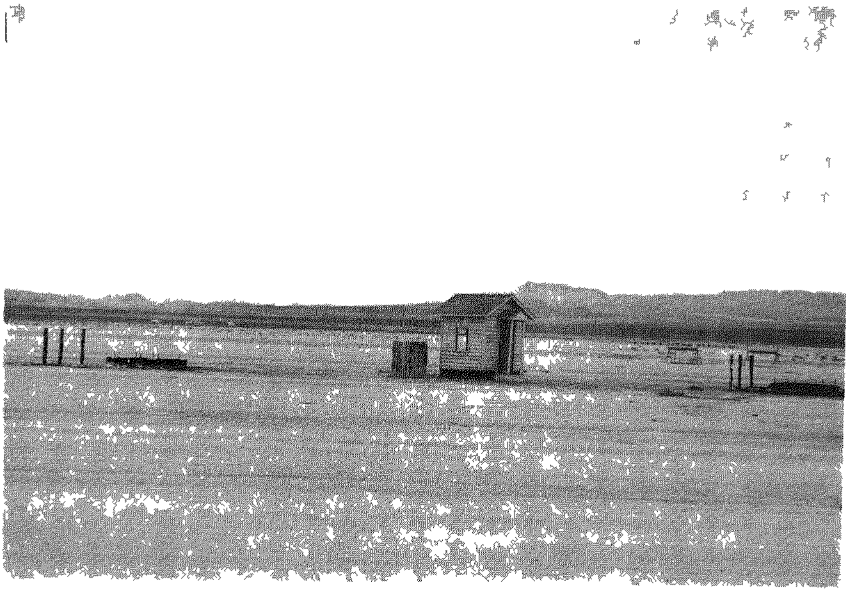

Figure 7.83 Wooden test houses after exposure to the nuclear explosion

important criterion of the probability of fire spread is the distance between buildings. It is evident, from general considerations, that the lower the building density or "built-upness" of an area, the less will be the probability that fire will spread from one structure to another. Further, the larger the spaces between buildings the greater the chances that the fire can be extinguished.

7.87 The curve in Fig. 7.87 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. The results will be dependent, to some extent, upon the types of structures involved, e. g., whether they are fire-resistive or not, as well as upon the damage caused by the blast wave (§ 7.79). It should be noted that Fig. 7.87 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

7.88 Another aspect of fire spread is the development of mass fires in a forest following primary ignition of dried leaves, grass, and rotten wood by the thermal radiation. Some of the factors which will influence the growth of such fires are the moisture content of the trees,

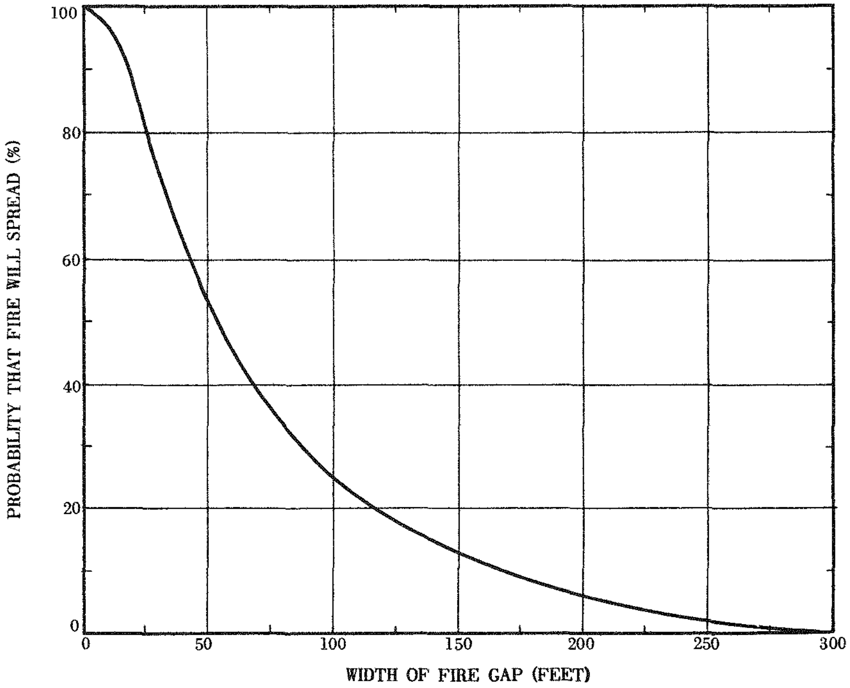

Figure 7.87. Width of gap and probability of fire spread.

topography, and meteorological conditions. Low atmospheric humidity, strong winds, and steep terrain favor the development of forest fires. In general, a deciduous forest, particularly when in leaf, may be expected to burn less rapidly and with less intensity than a forest of coniferous trees. Green leaves and the trunks of trees would act as shields against thermal radiation, so that the number of points at which ignition occurs in a forest may well be less than would appear at first sight.

INCENDIARY EFFECTS IN JAPAN

The Nuclear Bomb as an Incendiary Weapon

7.89 The incendiary effects of a nuclear explosion do not present any especially characteristic features. In principle, the same over-all result, as regards destruction by fire and blast, might be achieved by the use of conventional incendiary and high-explosive bombs. It has been estimated, for example, that the fire damage to buildings and other structures suffered at Hiroshima could have been produced by about 1,000 tons of incendiary bombs distributed over the city. It can be seen, however, that since this damage was caused by a single nuclear bomb of only 20 kilotons energy yield, nuclear weapons are capable of causing tremendous destruction by fire, as well as by blast.

7.90 Evidence was obtained from the nuclear explosions over Japan that the damage by fire is much more dependent upon local terrain and meteorological conditions than are blast effects. At both Hiroshima and Nagasaki the distances from ground zero at which particular types of blast damage were experienced were much the same. But the range of incendiary effects was quite different. In Hiroshima, for example, the total area severely damaged by fire, about 4.4 square miles, was roughly four times as great as in Nagasaki. One contributory cause was the irregular layout of Nagasaki as compared with Hiroshima; also greater destruction could probably have been achieved by a change in the point of burst. Nevertheless, an important factor was the difference in terrain, with its associated building density. Hiroshima was relatively flat and highly built up, whereas Nagasaki had hilly portions near ground zero that were bare of structures.

Origin and Spread of Fires in Japan

7.91 Definite evidence was obtained from Japanese observers that the thermal radiation caused thin, dark cotton cloth, such as the black-out curtains that were in common use during the war, thin paper, and dry, rotted wood to catch fire at distances up to 3,500 feet (0.66 mile) from ground zero (about 35 calories per square centimeter). It was reported that a cedar bark roof farther out was seen to burst into flame, apparently spontaneously, but this was not definitely confirmed. Abnormal enhanced amounts of radiation, due to reflection, scattering, and focusing effects, might have caused fires to originate at isolated points (Fig. 7.91).

7.92 Interesting evidence of the ignition of sound wood was found about a mile from ground zero at Nagasaki, where the thermal energy was approximately 15 calories per square centimeter. A light piece of wood, similar to the flat side of an orange crate, had its front surface charred. In addition, however, blackening was observed through cracks and nail holes, where the thermal radiation would not have penetrated, and also around the edges adjoining the charred surface. A possible explanation is that the exposed surface of the wood had actually ignited, due to the heat from the thermal radiation, and the flames had spread through the cracks and holes around the edges for several seconds, before they were extinguished by the blast wind.

7.93 From the evidence of charred wood found at both Hiroshima and Nagasaki, it was originally concluded that such wood had actually been ignited by thermal radiation and that the flames were subsequently extinguished by the blast. But it now seems more probable that, apart from some exceptional instances, such as that just described, there was no actual ignition of the wood. The absorption of the thermal radiation caused charring in sound wood but the temperatures were generally not high enough for ignition to occur (§ 7.34). Rotted and checked wood and excelsior, however, have been known to burn completely, and the flame is not greatly affected by the blast wave.

7.94 It is not known to what extent thermal radiation contributed to the initiation of fires in the nuclear bombings in Japan. It is possible that, up to a mile or so from ground zero, some fires may have originated from secondary causes, such as upsetting of stoves, electrical short-circuits, broken gas lines, and so on, which were a direct effect of the blast wave. A number of fires in industrial plants were initiated by furnaces and boilers being overturned, and by the collapse of buildings on them.

7.95 Once the fires had started, there were several factors, directly related to the destruction caused by the nuclear explosion, that influenced their spreading. By breaking windows and blowing in or

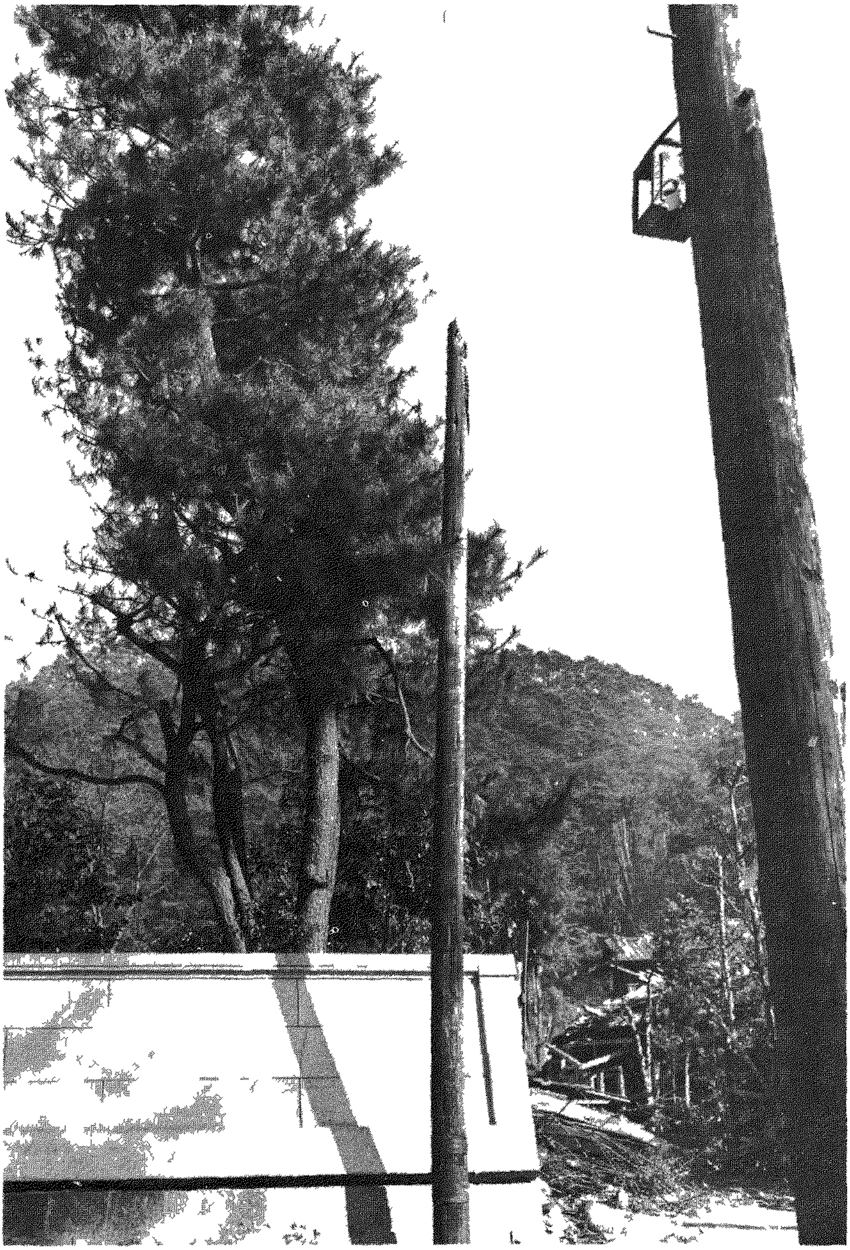

Figure 7.91 The top of a wood pole was reported as being ignited by the thermal radiation (1.25 miles from ground zero at Hiroshima). Note the unburned surroundings; the nearest burned building was 360 feet away.

damaging fire shutters (Fig. 7.95), by stripping wall and roof sheathing, and collapsing walls and roofs, the blast made many buildings more vulnerable to fire. Noncombustible (fire-resistive) structures were often left in a condition favorable to the internal spread of fires by damage at stairways, elevators, and in firewall openings, as well as by the rupture and collapse of floors and partitions (Fig. 4.85d).

Figure 7.95. Fire shutters in building blown in or damaged by the blast; shutter at center probably blown outward by blast passing through building (0.57 mile from ground zero at Hiroshima).

7.96 On the other hand, when combustible frame buildings were blown down, they did not burn as rapidly as they would have done had they remained standing. Further, the noncombustible debris produced by the blast frequently covered and prevented the burning of combustible material. There is some doubt, therefore, whether, on the whole, the effect of the blast was to facilitate or to hinder the development of fires at Hiroshima and Nagasaki.

7.97 Although there were firebreaks, both natural, e. g., rivers and open spaces, and artificial, e. g., roads and cleared areas, in the Japanese cities, they were not very effective in preventing the fires from spreading. The reason was that fires often started simultaneously on both sides of the firebreaks, so that they could not serve their intended purpose. In addition, combustible materials were frequently strewn across the firebreaks and open spaces, such as yards and street areas, by the blast, so that they could not prevent the spread of fires. Nevertheless, there were a few instances where firebreaks assisted in preventing the burn-out of some fire-resistive buildings.

7.98 One of the important aspects of the nuclear bomb attacks on Japan was that, in the large area that suffered simultaneous blast damage, the fire departments were completely overwhelmed. It is true that the fire-fighting services and equipment were poor by American standards, but it is doubtful if much could have been achieved, under the circumstances, by more efficient fire departments. At Hiroshima, for example, 70 percent of the fire-fighting equipment was crushed in the collapse of fire houses, and 80 percent of the personnel were unable to respond. Even if men and machines had survived the blast, many fires would have been inaccessible because of the streets being blocked with debris. For this reason, and also because of the fear of being trapped, a fire company from an area which had escaped destruction was unable to approach closer than 6,600 feet (1.25 miles) from ground zero at Nagasaki. It was almost inevitable, therefore, that all buildings within this range would be destroyed.

7.99 Another contributory factor to the destruction by fire was the failure of the water supply in both Hiroshima and Nagasaki. The pumping stations were not largely affected, but serious damage was sustained by distribution pipes and mains, with a resulting leakage and drop in available water pressure. Most of the lines above ground were broken by collapsing buildings and by heat from the fires which melted the pipes. Some buried water mains were fractured and others were broken due to the collapse or distortion of bridges upon which they were supported (§4.113).

Fire Storm in Hiroshima

7.100 About 20 minutes after the detonation of the nuclear bomb at Hiroshima, there developed the phenomenon known as "fire storm." This consisted of a wind which blew toward the burning area of the city from all directions, reaching a maximum velocity of 30 to 40 miles per hour about 2 to 3 hours after the explosion, decreasing to light or moderate and variable in direction about 6 hours after. The wind was accompanied by intermittent rain, light over the center of the city and heavier about 3,500 to 5,000 feet (0.67 to 0.95 mile) to the north and west. Because of the strong inward draft at ground level, the fire storm was a decisive factor in limiting the spread of the fire beyond the initial ignited area. It accounts for the fact that the radius of the burned-out area was so uniform in Hiroshima and was not much greater than the range in which fires started soon after the explosion. However, virtually everything combustible within this region was destroyed.

7.101 It should be noted that the fire storm is by no means a special characteristic of the nuclear bomb. Similar fire storms have been reported as accompanying large forest fires in the United States, and especially after incendiary bomb attacks in both Germany and Japan during World War II. The high winds are produced largely by the updraft of the heated air over an extensive burning area. They are thus the equivalent, on a very large scale, of the draft of a chimney under which a fire is burning. The rain associated with a fire storm is apparently due to the condensation of moisture on particles from the fire when they reach a cooler area.

7.102 The incidence of fire storms is dependent on the conditions existing at the time of the fire. Thus, there was no such definite storm over Nagasaki, although the velocity of the southwest wind, blowing between the hills, increased to 35 miles an hour when the conflagration had become well established, perhaps about 2 hours after the explosion. This wind tended to carry the fire up the valley in a direction where there was nothing to burn. Some 7 hours later, the wind had shifted to the east and its velocity had dropped to 10 to 15 miles per hour. These winds undoubtedly restricted the spread of fire in the respective directions from which they were blowing. The small number of dwellings exposed in the long narrow valley running through Nagasaki probably did not furnish sufficient fuel for the development of a fire storm as compared to the many buildings on the flat terrain at Hiroshima.

TECHNICAL ASPECTS OF THERMAL RADIATION[6]

Spectral Distribution of Energy from Ball of Fire

7.103 If it can be assumed that the ball of fire in a nuclear explosion, like the sun, behaves rather like a black body, i. e., as a perfect radiator, the distribution of the thermal radiation energy over the

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[6] The remaining sections of this chapter may be omitted without loss of continuity.

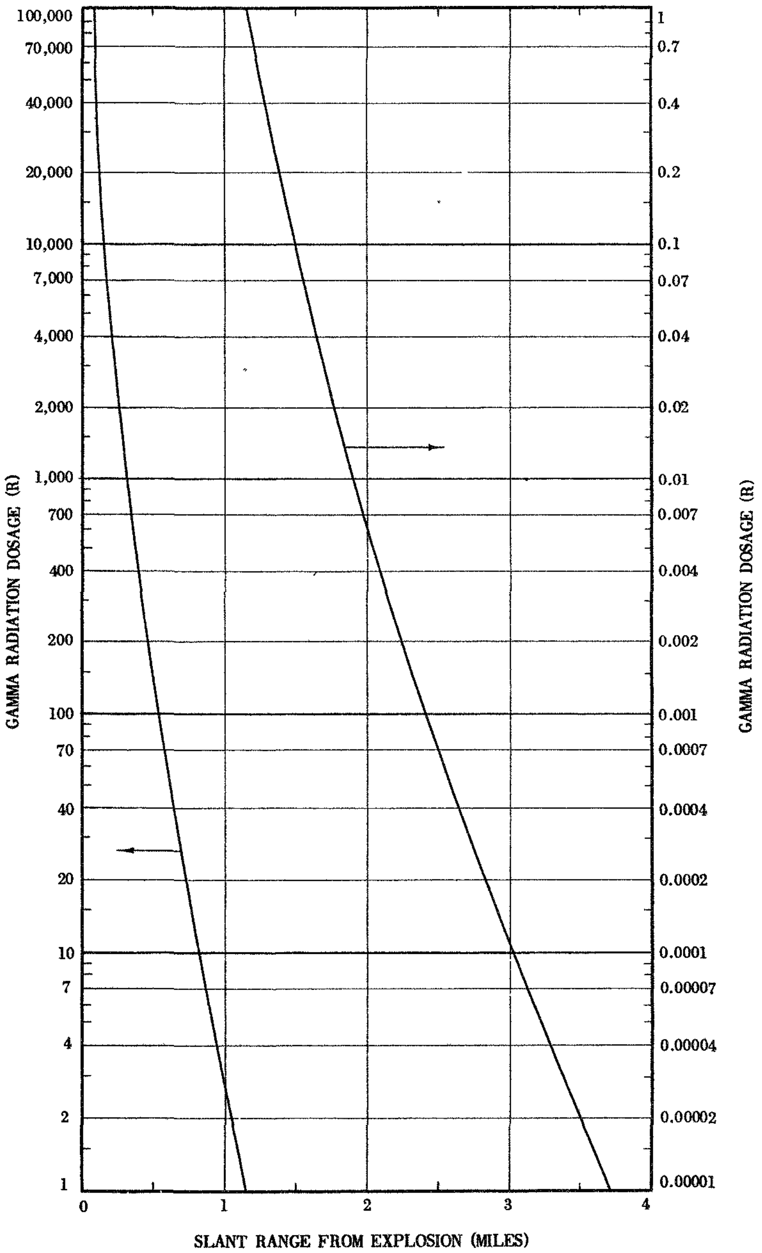

Figure 8.35a. Initial gamma radiation dosage for a 1-kiloton air burst.

is, a fair estimate can be made by assuming that the product of the half-value layer in inches and the density in pounds per cubic foot is about 800.

TABLE 8.44

APPROXIMATE HALF-VALUE LAYER THICKNESSES OF MATERIALS FOR INITIAL GAMMA RADIATION

Material	Density (lb/cu ft)	Half-value thickness (inches)	Product
Steel	490	1. 5	735
Concrete	144	6. 0	864
Earth	100	7. 5	750
Water	62. 4	13	811
Wood	34	23	782

8.46 The attenuation factor of a given shield, that is, the ratio of the dose falling upon the shield to that which would be received behind the shield, can be readily calculated from the number of half-value thicknesses, together with the data in Table 8.44. For example, a 30-inch thick shield of earth will contain $30/7\frac{1}{2}=4.0$ half-value

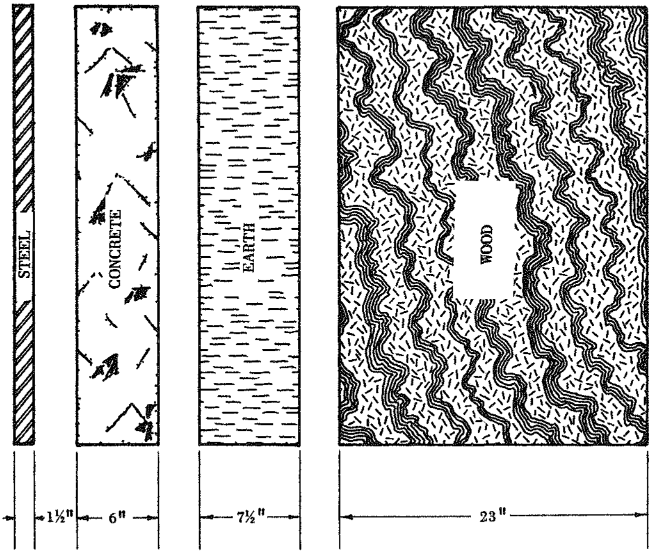

Figure 8.45 Comparison of the half-value layer thicknesses.

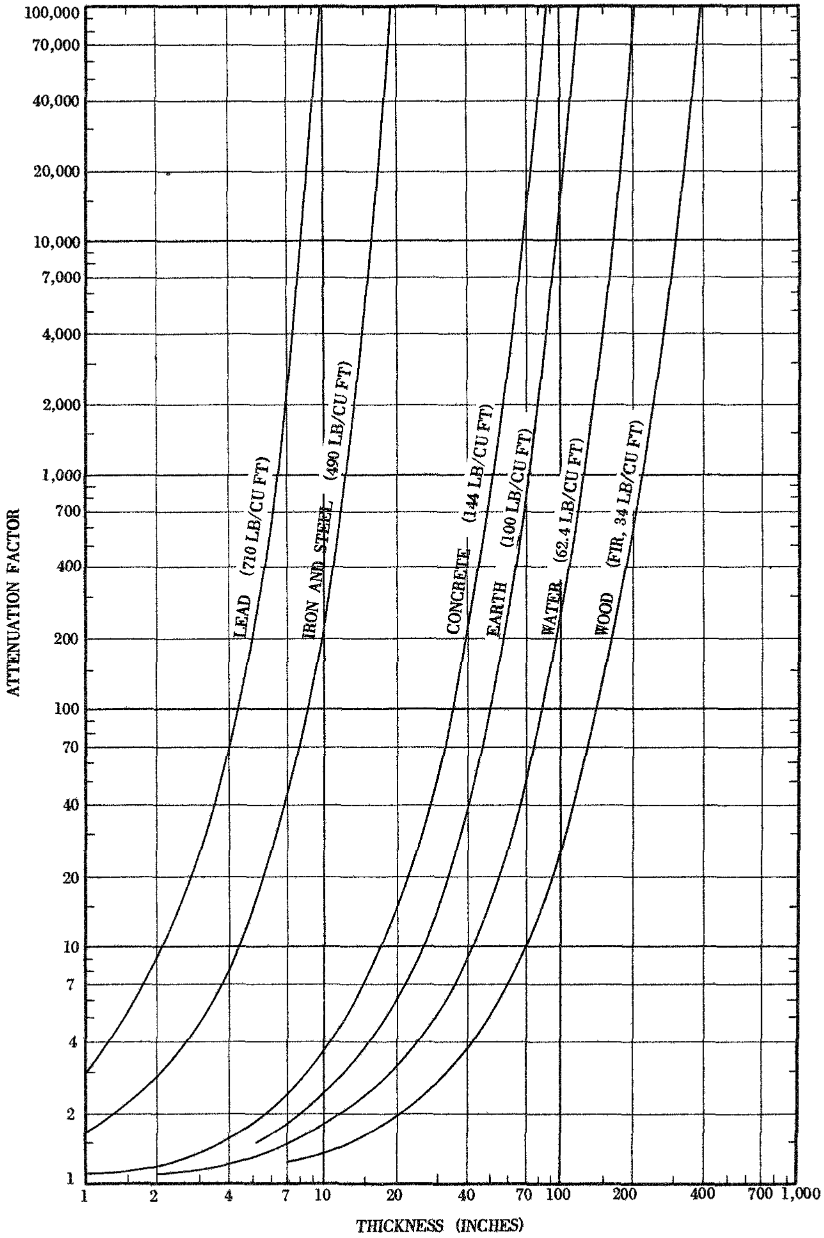

Figure 8.47. Attenuation of initial gamma radiation.

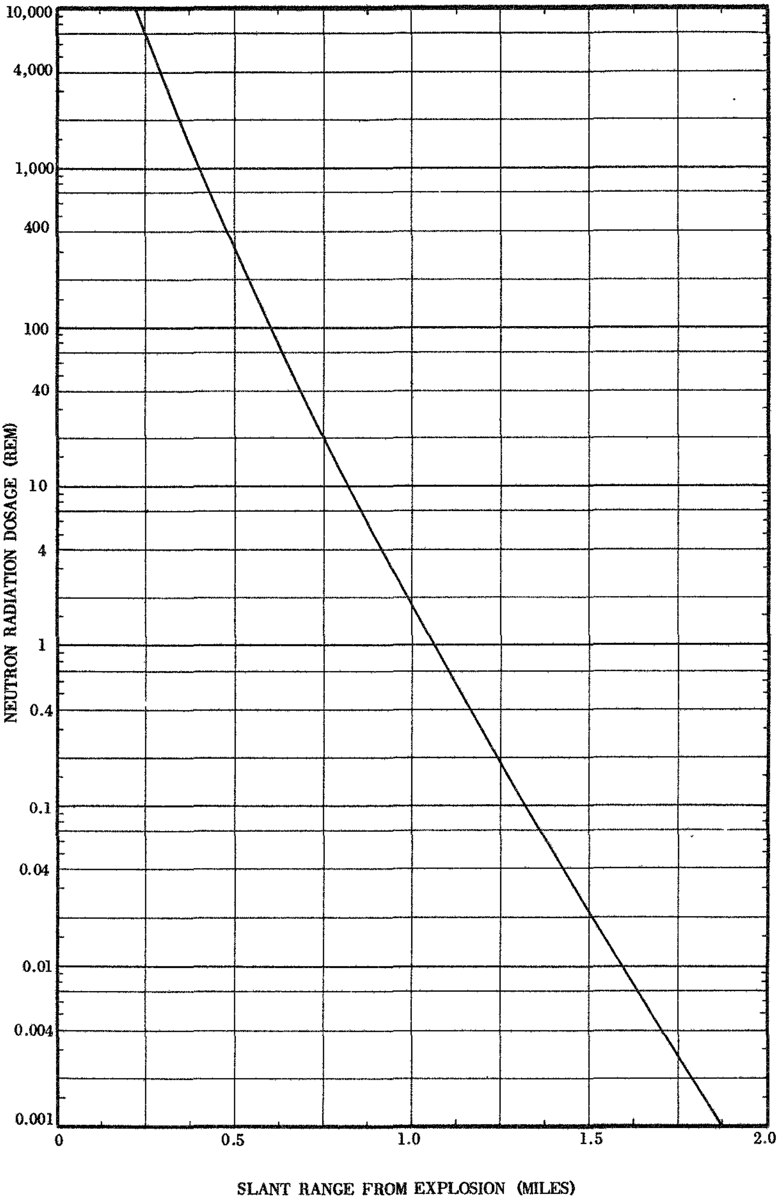

Figure 8.71. Neutron biological dosage for a 1-kiloton air burst.

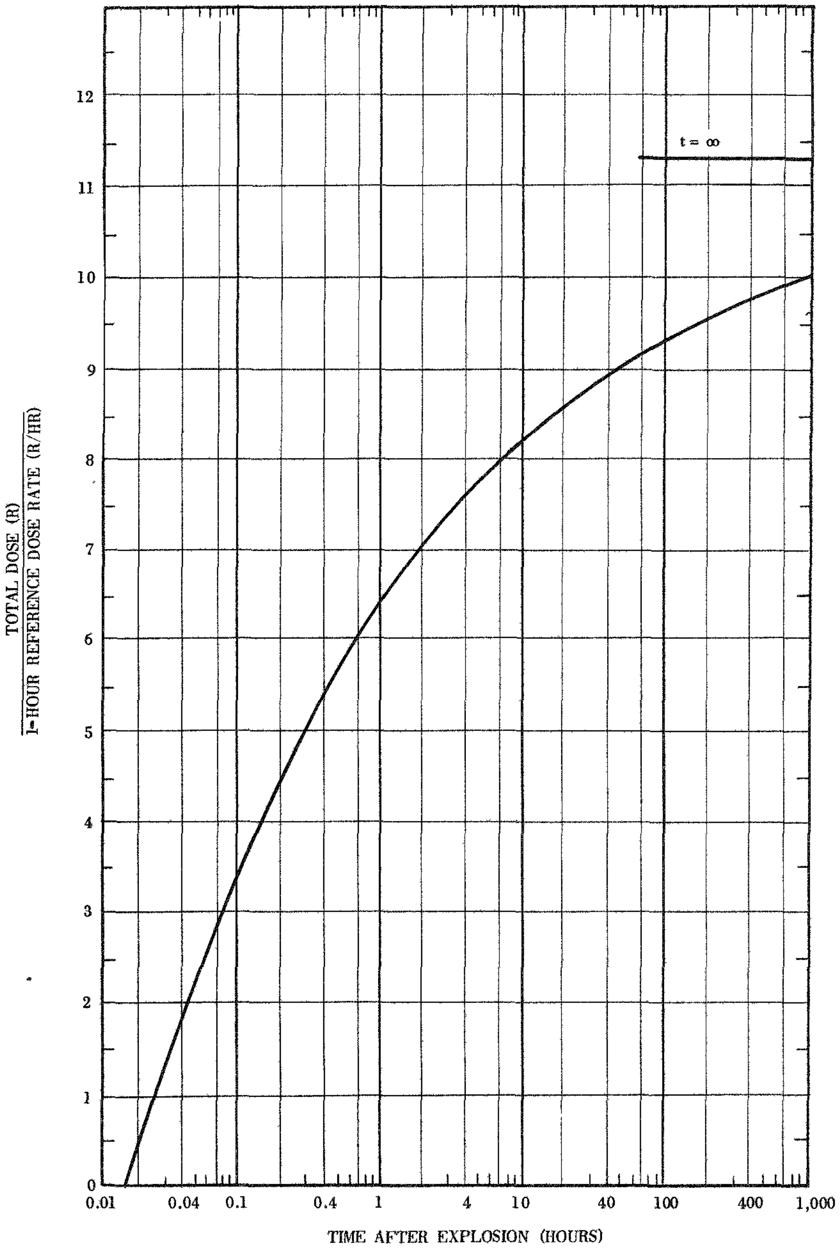

Figure 9.12. Accumulated total dose of residual radiation from fission products from 1 minute after the explosion.

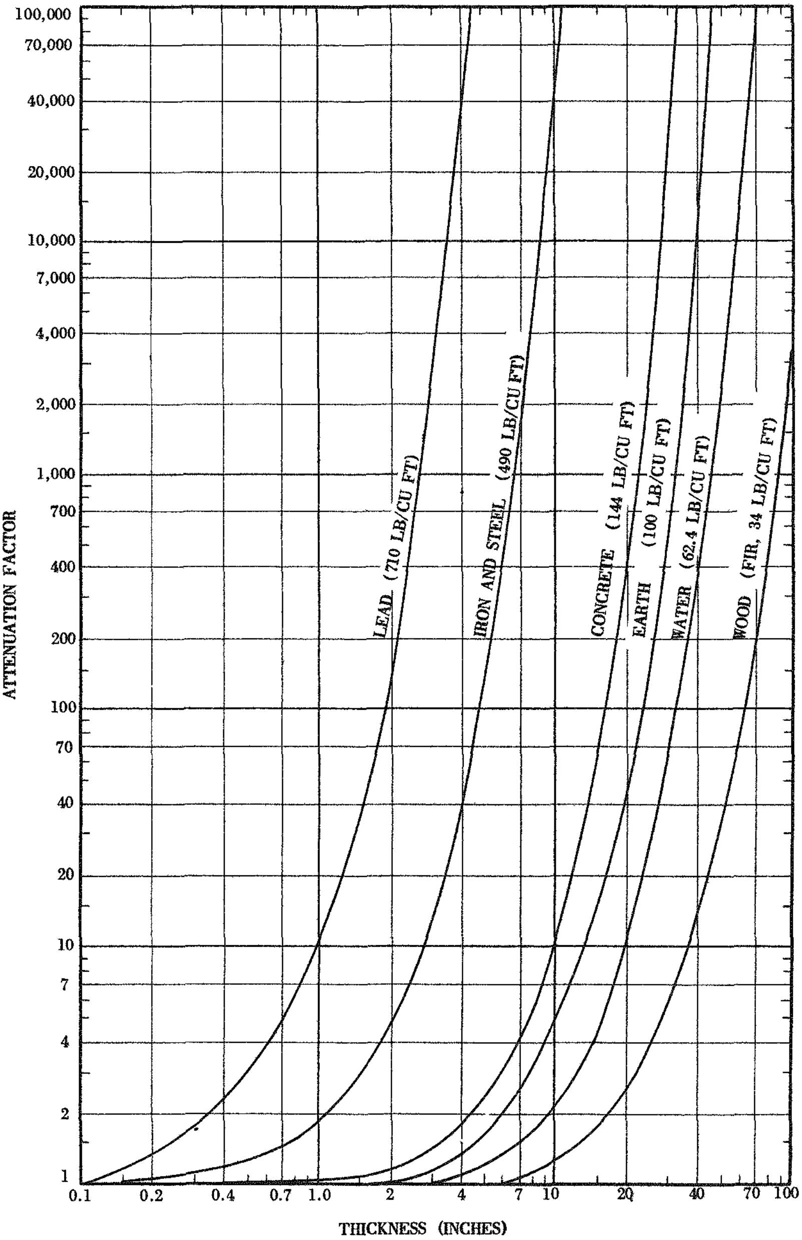

Figure 9.36. Attenuation of fission product radiation.

9.37 From the practical standpoint, it is of interest to record the attenuation factors that might be expected inside various structures. Two factors are responsible for this attenuation. First, there is the effect of distance, because the source of the radiation will be mostly outside, e. g., on the roof or in the street; and second, there is partial absorption of the radiation by the roof and walls. The approximate values given in Table 9.37 have been estimated partly from calculations and partly on the basis of field measurements. It will be noted that in the basement of a frame house the residual gamma radiation is reduced to about one-tenth of its value outside the house. A 3-foot layer of earth attenuates the radiations to one-thousandth (or less) of the intensity it would otherwise have at the same location.

TABLE 9.37

ESTIMATED ATTENUATION FACTORS IN STRUCTURES FOR RESIDUAL GAMMA RADIATION

Type of Structure	Approximate attenuation factor
Frame house:	
First floor	2
Basement	10
Multistory, reinforced concrete:	
Lower floors (away from windows)	10
Basement (surrounded by earth)	*1, 000
Shelter below grade:	
3 feet of earth	*1, 000

*Or more.

ASPECTS OF RADIATION EXPOSURE

ACUTE AND CHRONIC EXPOSURE

9.38 In considering the injurious effects on the body of gamma radiations from external sources, it is necessary to distinguish between an "acute" (or "one-shot") exposure and a "chronic" exposure. In an acute exposure the whole radiation dose is received in a relatively short interval of time. This is the case, for example, in connection with the initial nuclear radiation considered in the preceding chapter. It is not possible to define an acute dose precisely, but it may be

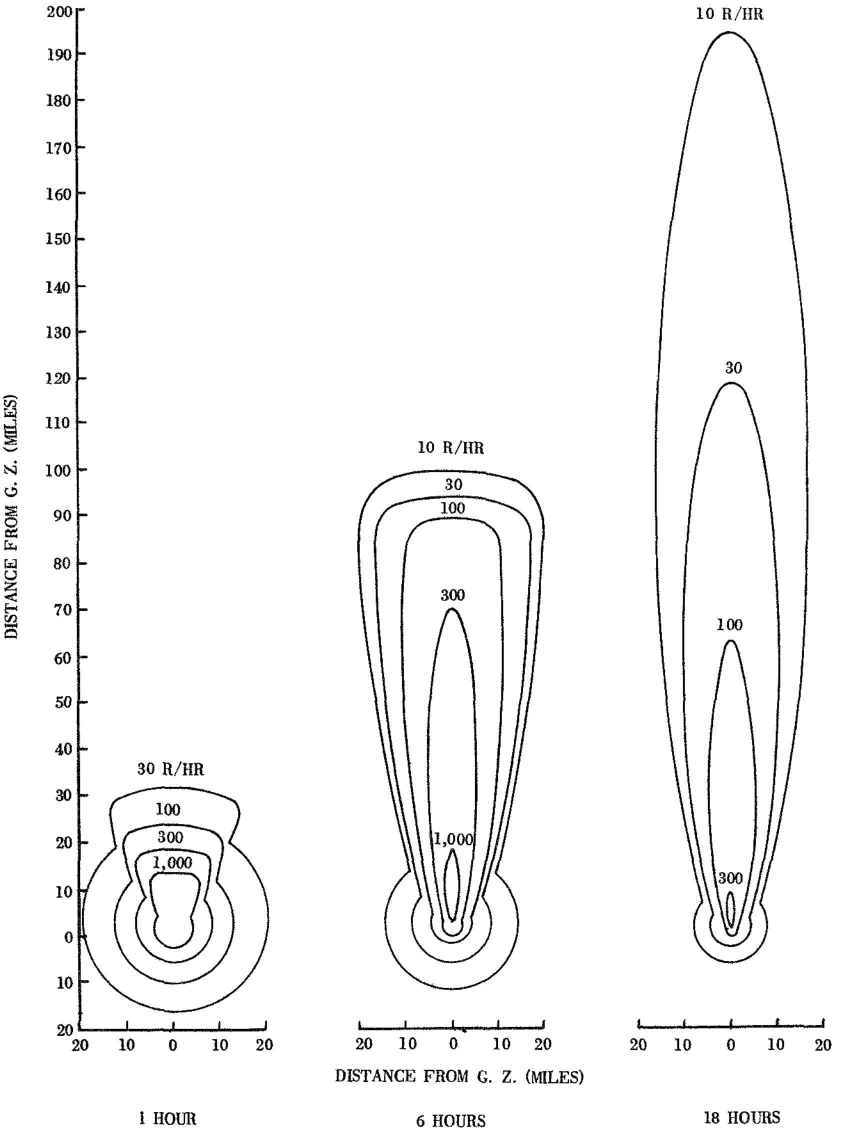

Figure 9.63a. Dose rate contours from fallout at 1, 6, and 18 hours after a surface burst with fission yield in the megaton range (15 mph effective wind).

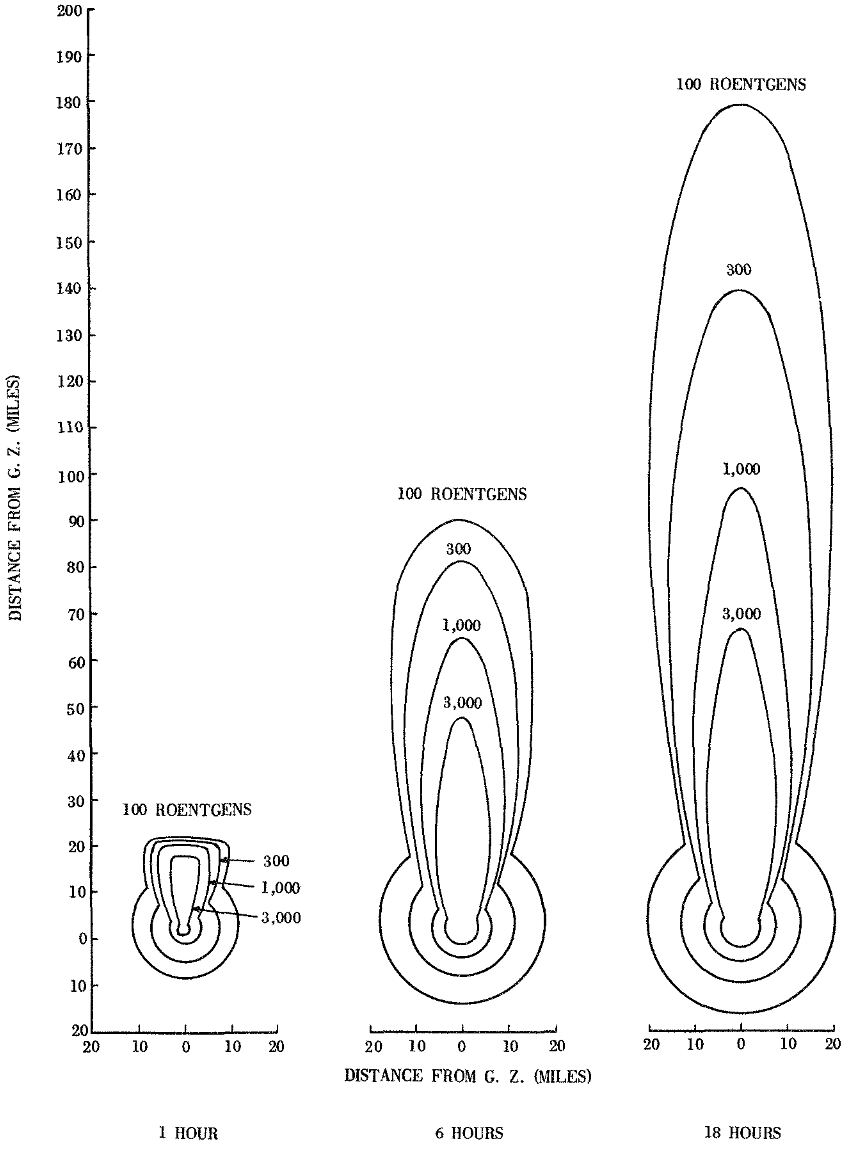

Figure 9.63b. Total (accumulated) dose contours from fallout at 1, 6, and 18 hours after a surface burst with fission yield in the megaton range (15 mph effective wind).

HIGH FISSION-YIELD EXPLOSIONS

9.71 The contour dimensions for a number of hypothetical (reference) 1-hour dose rates, relating to a 1-megaton fission yield surface burst, are given in Table 9.71, based on an effective wind velocity of 15 miles per hour. The data are obtained, as before, by using the fission product decay curve (Fig. 9.8), or an equivalent mathematical expression, to determine what the dose rate would have been at 1 hour after the explosion, if the fallout at each location had been complete at that time. The upwind extent of any particular dose rate contour given in the table is obtained by subtracting the ground zero (GZ) circle displacement from the ground zero circle radius. For example, the 10 roentgens per hour reference contour extends 11.0−1.65=9.35 miles upwind.

TABLE 9.71

APPROXIMATE RESIDUAL RADIATION 1-HOUR (REFERENCE) DOSE-RATE CONTOURS ON GROUND FOR 1-MEGATON SURFACE BURST

Dose rate (r/hr)	Radius of GZ circle (miles)	Displacement of center of GZ circle (miles)	Downwind distance (miles)	Crosswind distance (miles)
3,000	0. 43	0. 60	22	3. 1
1,000	1. 4	0. 80	40	6. 8
300	2. 8	1. 02	70	11. 8
100	4. 7	1. 24	114	16. 7
30	7. 5	1. 46	183	22. 8
10	11. 0	1. 65	317	34. 1

9.72 A more complete (idealized) representation of the contour pattern of the 1-hour (reference) dose rates, for the conditions stated above, is given in Fig. 9.72. Because of the lack of symmetry in the terrain and the effects of winds, the elliptical fallout contours for the residual radiation will not look exactly like those in Fig. 9.72. However, for representation purposes the contours are idealized in accordance with the form shown in Fig. 9.61.

9.73 It is of the utmost importance that the significance of the contours in Fig. 9.72 should not be misunderstood. The fact that the 1-hour (reference) dose rates extend to great distances from ground zero must not be taken to imply that such dose rates exist at 1 hour

(Text continued on page 420)

(Text continued from page 417)

after the explosion. In actual fact, of course, very little of the area shown will have received any fallout at this time. In most regions, as explained in § 9.64, *et seq.*, several hours will elapse before the fallout arrives. The hypothetical 1-hour (reference) dose rate is, nevertheless, very useful for calculations, as shown in the example facing Fig. 9.72.

SCALING

9.74 The residual radiation contours near ground zero for a surface explosion of any specified energy yield can be derived from Tables 9.68 and 9.71 or Fig. 9.72 by the use of approximate scaling laws. For simplicity, it will be assumed that the effective wind is the same in all instances. If the 1-hour (reference) dose rate is R roentgens per hour at a distance d from ground zero for a surface explosion of W megatons fission yield, then according to the approximate scaling law,

$$R=R_0\times W^{1/3} \text{ at a distance } d=d_0\times W^{1/3},$$

where R_0 is the 1-hour (reference) dose rate at a distance d_0 from ground zero in a surface explosion of 1 megaton fission yield. Instead of d (and d_0) representing a distance from ground zero, the same scaling rule will apply to any of the contour dimensions, e. g., radius and displacement of ground zero circles, and downwind and crosswind distances.

9.75 In other words, the contours for a fission yield of W megatons can be obtained by multiplying the data in Table 9.71, including distances and dose rates, by the factor $W^{1/3}$. This simple cube root scaling law has been found to give reasonably good results for fission energy yields between about 0.1 megaton (100 kilotons) and 10 megatons. For yields less than 100 kilotons it may be preferable to scale in a similar manner from data given in Table 9.68 for a 20-kiloton surface burst. In this case, the contours for a fission yield of W kilotons can be obtained by multiplying the data in Table 9.68, including the dose rates, by the factor $(W/20)^{1/3}$. In general, if the atomic cloud does not reach the tropopause or is not significantly flattened by it, scaling should be done from the 20-kiloton surface burst data in Table 9.68; however, if the cloud does reach the tropopause, scaling from the 1-megaton values in Table 9.71 (or Fig. 9.72) will give better results.

9.76 The scaling procedures described above will apply (approximately) provided the effective wind velocity is always 15 miles per hour. If the actual effective wind velocity is different from this value, an approximate correction can be made in the following manner,

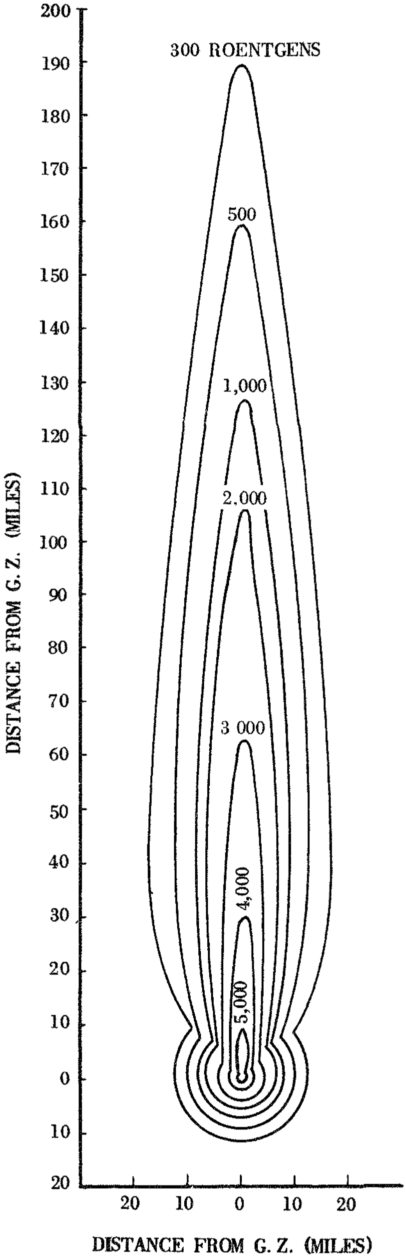

Figure 9.87. Idealized total (accumulated) dose contours from fallout in first 36 hours after the high yield explosion at Bikini Atoll on March 1, 1954.

vided by the data in Table 9.108, obtained after the Bikini BAKER test. Thus, within 2 or 3 days the radioactivity had spread over an area of about 50 square miles, but the maximum radiation dose rate was then so low that the area could be traversed without danger.

TABLE 9.108

DIMENSIONS AND DOSE RATE OF CONTAMINATED WATER AFTER THE 20-KILOTON UNDERWATER EXPLOSION AT BIKINI

Time after explosion (hours)	Contaminated area (square miles)	Mean diameter (miles)	Maximum dose rate (roentgens per hour)
4	16. 6	4. 6	3. 1
38	18. 4	4. 8	0. 42
62	48. 6	7. 9	0. 21
86	61. 8	8. 9	0. 042
100	70. 6	9. 5	0. 025
130	107	11. 7	0. 008
200	160	14. 3	0. 0004

9.109 In addition to the factors mentioned above, the settling of fission products to the bottom of the lagoon contributed to the decrease in activity after the BAKER test. From an examination of bottom material made a few days after the explosion, it appeared that a considerable proportion of the bomb residues must have been removed from the water in this manner. The results indicated that the major deposition had taken place within a week of the underwater explosion, and that the area covered was then about 60 square miles. Although the total amount of radioactivity on the bottom of the lagoon was very high, it was so widely distributed that it did not represent a hazard to marine life. Observations made several months later indicated that there was little or no tendency for the contaminated material to spread. But this may be attributed, in part at least, to the landlocked nature of Bikini Lagoon.

TECHNICAL ASPECTS OF RESIDUAL NUCLEAR RADIATION[7]

DECAY OF FISSION PRODUCTS

9.110 The mixture of radioisotopes constituting the fission products is so complex that a mathematical representation of the rate of

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[7] The remaining sections of this chapter may be omitted without loss of continuity.

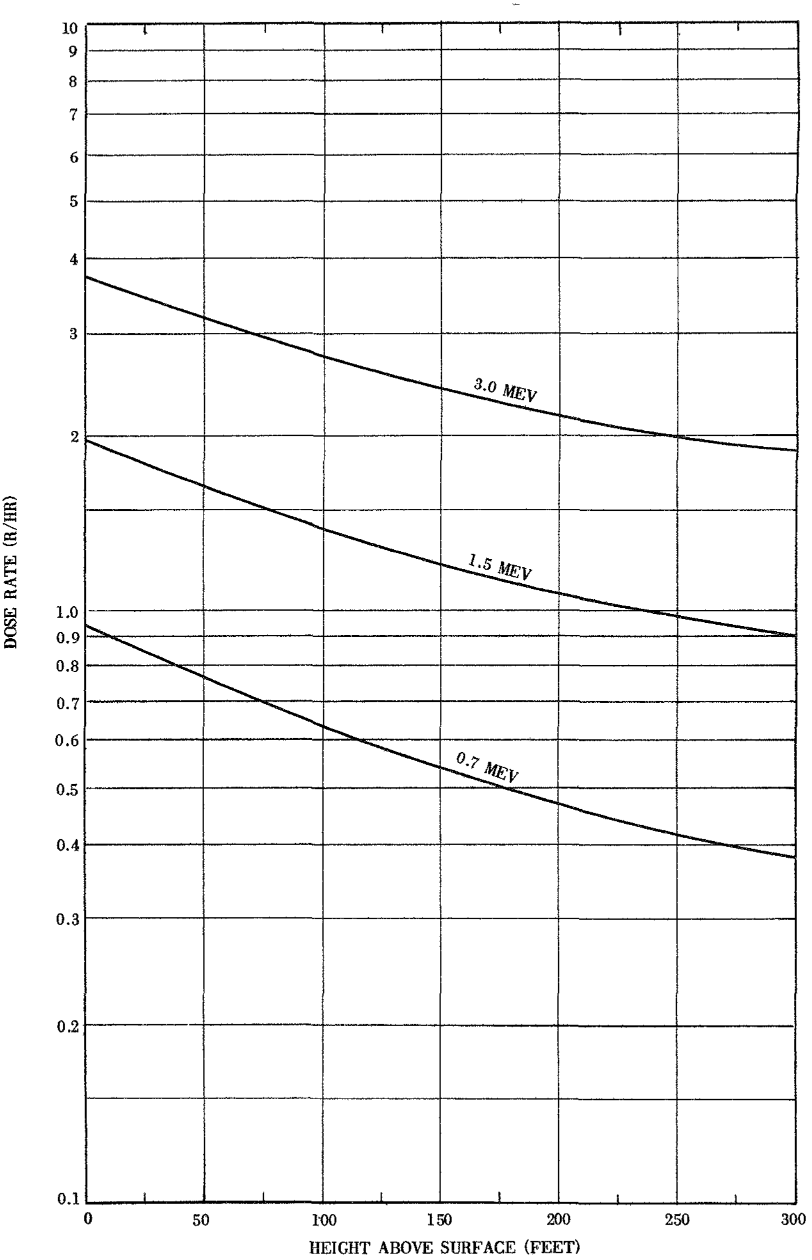

Figure 9.124a. Dose rate of gamma radiation near surface of water with uniform contamination density of 1 curie per cubic yard.

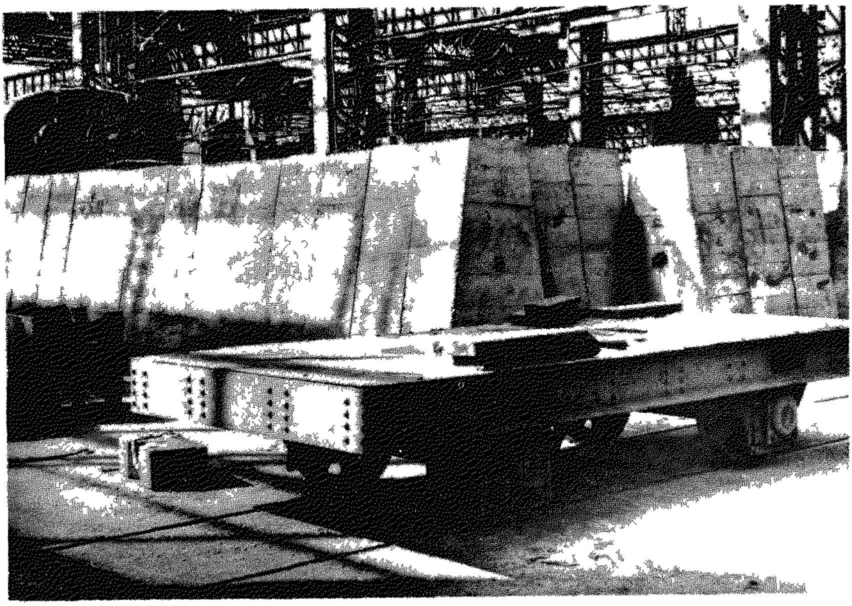

Figure 12.37a. Precast, reinforced-concrete blast walls (0.85 mile from ground zero at Nagasaki).

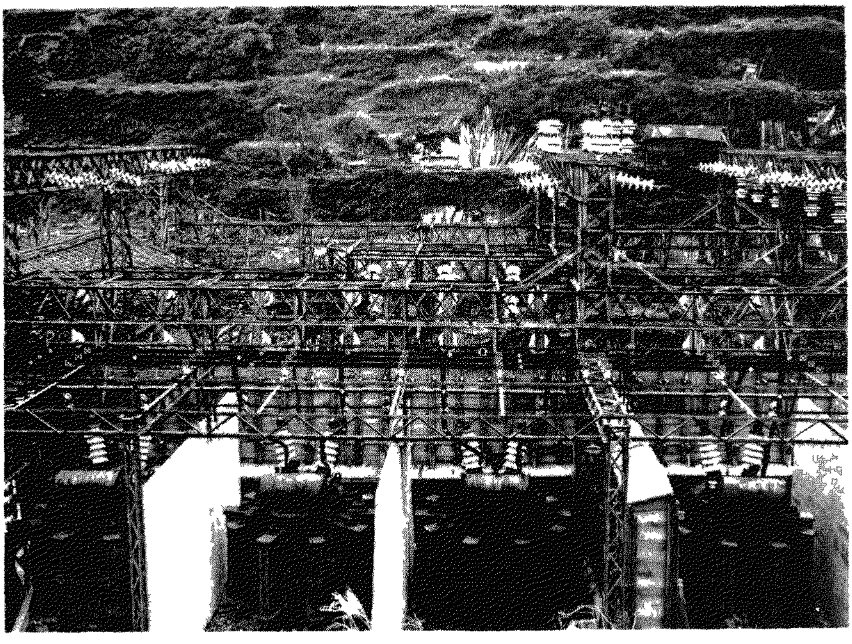

Figure 12.37b. Reinforced-concrete blast walls protecting transformers (1 mile from ground zero at Nagasaki).

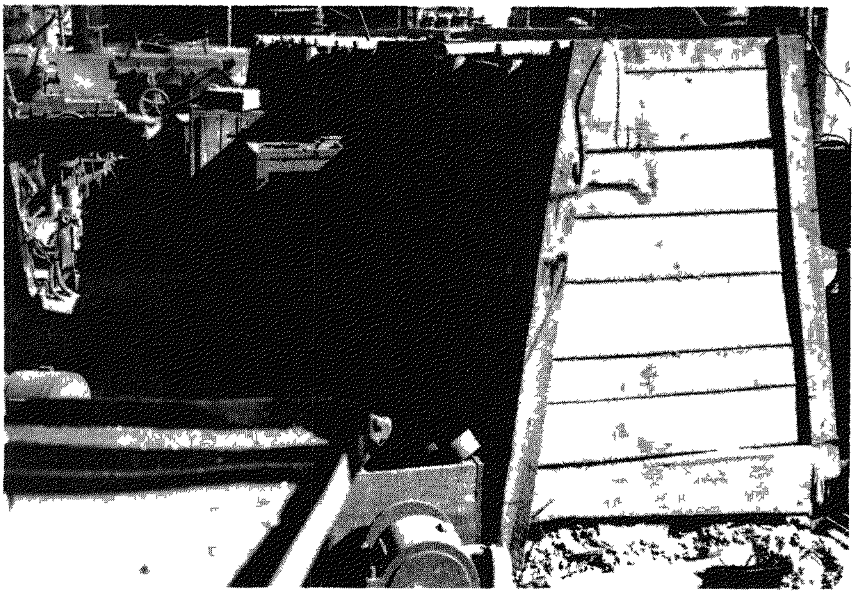

Figure 12.37c. Earth-filled, wooden blast walls protecting machinery (0.85 mile from ground zero at Nagasaki).

PROTECTION BY TRENCHES AND EARTH REVETMENTS

12.38 Although they are not strictly structures, in the sense used above, attention should be called to the significant protection that can be afforded by trenches and earth revetments, especially to drag-sensitive targets. A shallow pit provides little shielding, but pits or trenches that are deeper than the target have been found to be very effective in reducing the magnitude of the drag forces impinging on any part of the target. In these circumstances, the lateral loading is greatly reduced and the damage caused is restricted mainly to that due to the crushing action of the blast wave.

12.39 The only types of shielding against drag forces which have been found to be satisfactory so far are those provided by fairly extensive earth mounds (or revetments) and deep trenches, since these are themselves relatively invulnerable to blast. Such protective trenches are not recommended for use in cities, however, because of the damage that would result from debris falling into them. Although sandbag mounds have proved satisfactory for protection against conventional high explosives and projectiles, they are inadequate against nuclear blast because they may become damaging missiles.

Figure 12.40a. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

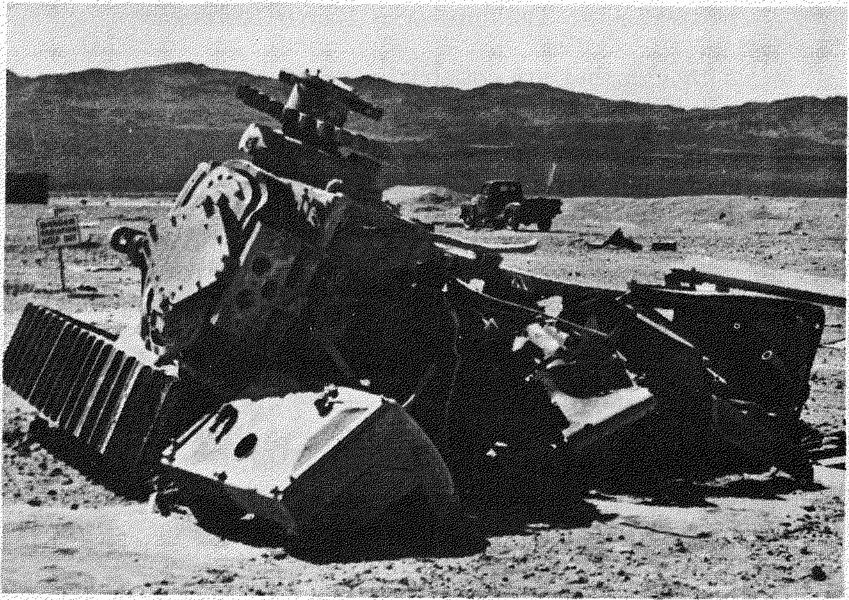

Figure 12.40b. Earth-moving equipment subjected to nuclear blast in open terrain (30 psi overpressure).

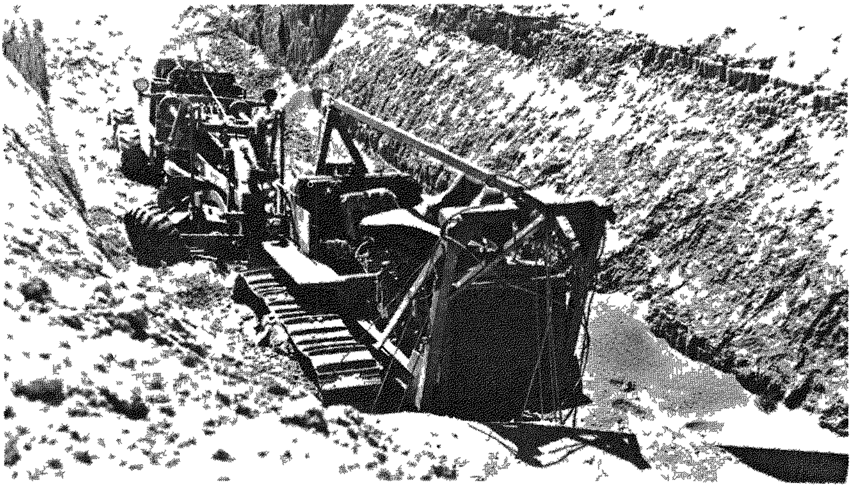

Figure 12 40c. Earth-moving equipment protected in deep trench at right angles to blast wave motion (30 psi overpressure).

12.40 The destruction caused by a nuclear explosion to two pieces of earth-moving equipment, which are largely drag-sensitive, is shown in Figs. 12.40a and b. Two similar pieces of equipment located in a deep trench, at the same distance from the explosion, are seen in Fig. 12.40c to have been essentially unharmed. It is important to mention that the main direction of the trench was at right angles to the motion of the blast wave. If the wave had been traveling in the same direction as the trench, the equipment would probably have been severely damaged. Consequently, in order to provide protection from drag forces, the orientation of the trench or earth revetment, with respect to the expected direction of the explosion, is of great importance.

Fire Protection

12.41 It was noted in Chapter VII that fires following a nuclear explosion may be started by thermal radiation and by secondary effects, such as overturning stoves and furnaces, rupture of gas pipes, and electrical short circuits. Fire-resistive construction and avoidance of fabrics and other light materials of inflammable character are essential in reducing fire damage. As shown by the tests described in § 7.82, a well-maintained house, with a yard free from inflammable rubbish, was less easily ignited by thermal radiation than a house that has not had adequate care.

12.42 The methods of fire-resistive design and of city planning are well known and the subject need not be treated here. A special requirement is the reduction of the chances of ignition due to thermal radiation by the avoidance of trash piles and other finely divided fuel as well as combustible, especially dark colored, materials that might be exposed at windows or other openings. It has been recommended, in this connection, that all such openings be shielded against thermal radiation from all directions. The simple device of whitewashing windows will greatly reduce the transmission of thermal radiation and so decrease the probability of fires starting in the interior of the building. Other practical possibilities are the use of metal venetian blinds, reflective coatings on the window glass, and nonflammable interior pull curtains.

12.43 To judge from the experience in Japan, where the distortion by heat of exposed structural frames was considerable, it would appear desirable that steel columns and other steel members be protected from fire, especially where the contents of the building are flammable or where the building is located adjacent to flammable structures. Further, narrow firebreaks in Japan were found to be of little value. It is vital, therefore, that such firebreaks as may be provided in city planning or by demolition must be adequate for a major conflagration. A minimum width of 100 feet has been suggested.

12.44 One of the most important lessons learned from the nuclear bomb attacks on Japan is the necessity for the provision of an adequate water supply for the control of fires. In Nagasaki, the water pressure was 30 pounds per square inch at the time of the explosion, but chiefly because of numerous breaks in house service lines it soon dropped to 10 pounds per square inch. On the day following the explosion the water pressure was almost zero. This drop in the pressure contributed greatly to the extensive damage caused by fire. The experience in Hiroshima was quite similar.

SHELTERS FOR PERSONNEL

INTRODUCTION

12.45 Ideally, a shelter for personnel might be required to provide protection against air blast, ground shock, thermal radiation, initial nuclear radiation (neutrons and gamma rays), and residual nuclear radiation from fallout (external and internal sources). Such an ideal shelter is, however, virtually impossible to attain, in view of the uncertainties mentioned in § 12.2. Thus, shelter design, like that of other types of structures, must inevitably represent a compromise involving an element of risk. For example, structures of special design (see § 12.53), located underground, can withstand blast overpressures of 100 pounds per square inch or more and can greatly attenuate nuclear radiation. With suitable ventilation systems they can also protect against fallout, as well as against chemical and biological warfare agents. But even these shelters would probably be destroyed if they were fairly close to ground zero in the event of either a surface burst or a shallow underground burst.

12.46 A variety of personnel shelters have been designed and several types have been subjected to nuclear test explosions. These shelters range from minor modifications to existing homes, for use by a small family, to special blast-resistant construction, for buildings housing fairly large groups of individuals. For houses with basements, simple, inexpensive shelters can provide additional protection that could mean survival in a nuclear attack. If there is no basement, other worthwhile measures can be taken, although they would cost more.

12.47 In the design of special shelters for the protection of personnel, underground (or earth-covered) structures are preferred, since they reduce the hazards from thermal and nuclear radiations, as well as from air blast, at a moderate cost. In the design of such shelters there are three fundamental problems which must always be considered; these are (1) the structural (engineering) design; (2) proper ventilation of the occupied areas; and (3) the provision of adequately protected entranceways.

12.48 Past experience from nuclear tests has indicated that standard engineering practices are adequate for the design of underground shelters which will withstand air blast overpressures of 100 pounds per square inch. If the particular situation is such that a smaller design pressure would appear to be adequate then, as a general rule, it will be found more economical to use a shallow underground or earth-covered shelter of a simpler type. For example, the light earth-covered or buried structures referred to in Table 6.12, would not be seriously damaged by blast overpressures of 20 to 30 pounds per square inch. More vulnerable to air blast than the structures themselves are the ducts and ventilating equipment, which bring in the air supply, and the doors, door frames, and entranceways. These consequently require special consideration.

12.49 To insure an adequate supply of uncontaminated air during the critical period of occupancy of the shelter, the ventilating equipment and filters must remain in operating condition. This requires that intake and exhaust ducts be provided with some type of blast-arresting devices. Such devices should reduce the intensity of the blast force to the extent that the mechanical equipment and filters will not be harmed, and also that it will not be a hazard to persons in the shelter.

12.50 The entranceways to the shelter must be at least large enough to allow free access for personnel, and possibly to accommodate vehicular traffic. In addition, it is particularly important that the doors be designed to resist collapse, since the entrance of the blast wave through an opening, such as a doorway, might cause a sudden pressure rise inside the structure to a level that would be harmful to the occupants. It is always desirable that each doorway into the shelter be associated with an entranceway so placed that it will act as a blast-arresting device and also provide protection against flying missiles which might damage the door.

Family-Type (Home) Shelters

12.51 It will be recalled from Chapter IV that, even when the houses exposed to the nuclear explosions were so severely damaged, by a blast overpressure of 5 pounds per square inch, as to be rendered useless, the basements suffered little damage. Since no appreciable amount of thermal radiation would penetrate and the depth of soil outside the house would result in a considerable attenuation of the nuclear radiation, it would appear that basements offer possibilities as home shelters. Several designs for basement shelters have been tested in Nevada.

12.52 In houses without basements or where the water table makes it difficult to construct a shelter below the ground, the bathroom may be designed so that it can serve as an indoor shelter. This can be achieved by making the walls and ceiling of reinforced concrete and strengthening the floor slab (see § 4.34). The window and door openings are protected by special blast doors. A shelter of this type will provide good protection against blast, up to 5 pounds per square inch overpressure, at least, and also against thermal radiation. The degree of protection against nuclear radiation depends primarily on the thickness of the concrete walls and ceiling; the greater the thickness, the better the protection.

UNDERGROUND PERSONNEL SHELTER

12.53 Where essential industrial, civic, or military activities must be maintained before, during, and after a nuclear attack, it might be desirable to have a group shelter which could be occupied continuously, although not necessarily by the same individuals. A shelter of this kind would be of the closed type and would have to be provided with a suitable ventilating system. As a result of various tests, it has been found that in "open" shelters, i. e., in shelters which are open to the entry of the blast, the peak overpressure of the blast wave is not very different from that outside. Some reduction can be achieved by suitable design of the entrance and by the use of baffles, but the general impression is that, in strategic locations, where high overpressures may be expected, open group shelters would not be adequate.

12.54 The general features of a closed, underground personnel shelter, that can accommodate some 30 individuals at a time, but can be extended to hold more, are shown in Fig. 12.54. The design is based on experience gained at various nuclear tests in which shelters of this type have withstood peak overpressures of about 100 pounds per square inch. It was also found, as expected, to produce considerable attenuation of both gamma rays and neutrons.[3]

12.55 The main shelter chamber has reinforced-concrete walls 15 inches thick; the floor slab has a thickness of 18 inches and that of the roof is 21 inches. The chamber is covered with packed earth to a depth of at least 5 feet. The entrance is by concrete steps, in two sections at right angles. Instead of extending in the direction shown in the figure, the entranceway may be turned through 180°, so as to make the whole lay-out more compact. The stairway at the ground level is closed by means of an 8-inch thick horizontal door made of structural steel and reinforced concrete. The door has four wheels and is track mounted. It is so designed that as it rolls closed it seats itself on steel bed plates on each side of the stairwell, so that the blast load is removed from the wheels and axles. A heavy jack is mounted on the underside of the ceiling of the stairwell, so that the door can be forced open in case there is an accumulation of debris in the well behind the door.

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[3] The shelter described here was conceived and planned by the Federal Civil Defense Administration, with the assistance of the Army Ballistics Research Laboratory, the Army Chemical Center, and the Armed Forces Special Weapons Project. The structural design was by Ammann and Whitney, Consulting Engineers, under contract to the Federal Civil Defense Administration.

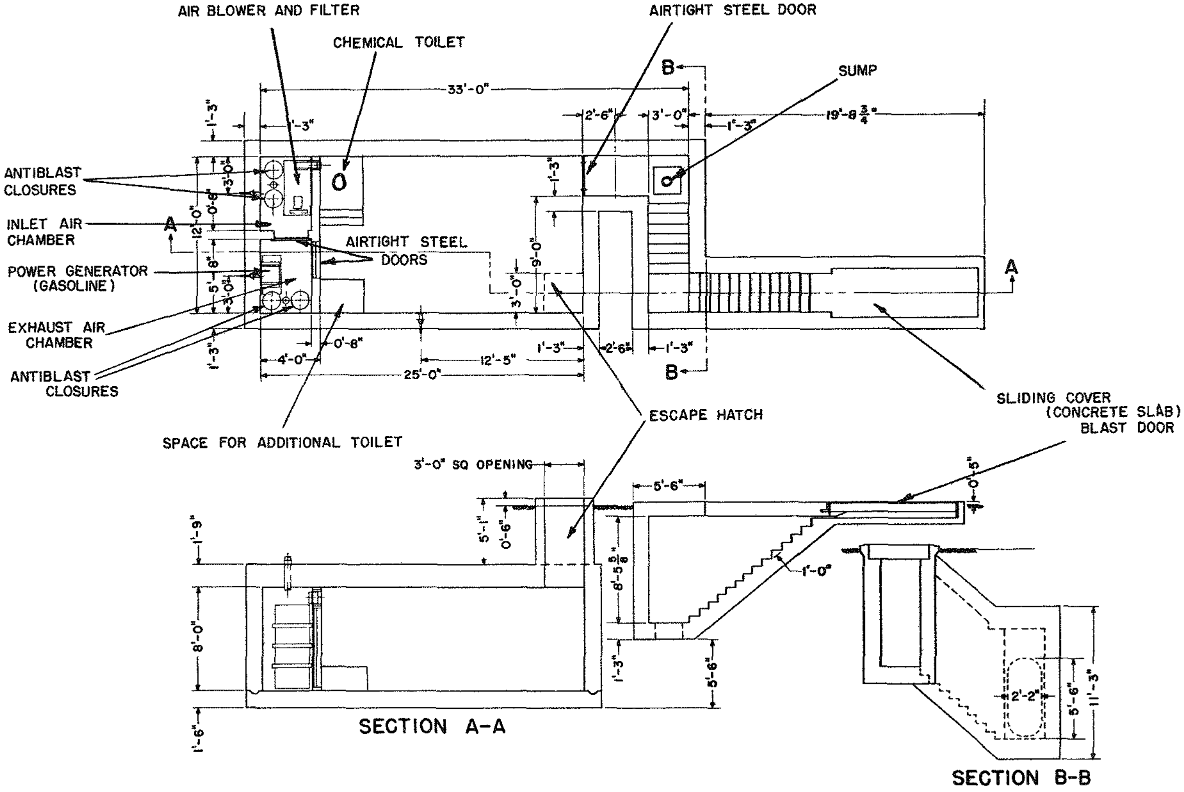

Figure 12.54. Sectional plan and section of underground personnel shelter.

12.56 Entrance to and exit from the shelter chamber is through a doorway fitted with a ½-inch steel, air tight (Navy bulkhead type) door. For emergency exit there is a 3 x 3-feet vertical escape hatch with a steel trap door. Normally the hatch is filled with washed and dried sand, but this can be run out and personnel can escape by climbing a vertical ladder in the wall.

12.57 The ventilation system for the shelter is contained in two compartments shown at the extreme left in Fig. 12.54. Air from outside enters the inlet chamber, passes through a filter, to remove particulate matter, e. g., fallout, as well as biological and chemical warfare agents, and is then blown into the shelter through ducts near the ceiling. The return air is expelled through the exhaust chamber. Both inlet and exhaust systems are fitted with special "anti-blast closures." These are so constructed that a sudden increase in the exterior pressure, due to the passage of a blast wave, will cause them to close almost instantaneously. Relief of the pressure by the negative phase of the blast wave will then open them again. The closures have been found to operate satisfactorily at peak overpressures up to at least 100 pounds per square inch.

12.58 The exhaust chamber also contains a gasoline-driven, electric generator for emergency use in the event of failure of the main power supply. An underground tank holds enough fuel for 10 days. At the other end of the shelter is a buried water tank to provide water for drinking purposes.

EMERGENCY SHELTERS

12.59 From experience gained in both nuclear and conventional explosions, there is little doubt that it is, as a general rule, more hazardous in the open than inside a structure. In an emergency, therefore, the best available shelter should be taken. Many subways would provide reasonably good emergency shelter, but they are to be found in a limited number of cities. As an alternative, that is more readily available, the basement of a building should be chosen. In this connection, a fire-resistive, reinforced-concrete or steel-frame structure is to be preferred, since there is less likelihood of a large debris load on the floor over the basement. Even basements of good buildings are not, however, an adequate substitute for a well-designed shelter, since the design live loads of floors over basements are usually small in comparison with the blast overpressure to which these floors may be subjected.

12.60 In the event of a surprise attack, when there is no opportunity to take shelter, immediate action could mean the difference between life and death. The first indication of an unexpected nuclear explosion would be a sudden increase of the general illumination. It would then be imperative to avoid the instinctive tendency to look at the source of light, but rather to do everything possible to cover all exposed parts of the body. A person inside a building should immediately fall prone and crawl behind or beneath a table or desk. This will provide a partial shield against splintered glass and other flying missiles. No attempt should be made to get up until the blast wave has passed, as indicated possibly by the breaking of glass, cracking of plaster, and other signs of destruction. The sound of the explosion also signifies the arrival of the blast wave.

12.61 A person caught in the open by the sudden brightness due to a nuclear explosion, should drop to the ground while curling up to shade the bare arms, hands, neck, and face with the clothed body. Although this action may have little effect against gamma rays and neutrons, it might possibly help in reducing flash burns due to thermal radiation. The degree of protection provided will vary with the energy yield of the explosion. As stated in § 7.53, it is only with high-yield weapons that evasive action against thermal radiation is likely to be feasible. Nevertheless, there is nothing to be lost, and perhaps much to be gained, by taking such action. The curled-up position should be held until the blast wave has passed.

12.62 If shelter of some kind, no matter how minor, e. g., in a doorway, behind a tree, or in a ditch, or trench can be reached within a second, it might be possible to avoid a significant part of the initial nuclear radiation, as well as the thermal radiation. But shielding from nuclear radiation requires a considerable thickness of material and this may not be available in the open. By dropping to the ground, some advantage may be secured from the shielding provided by the terrain and surrounding objects. However, since the nuclear radiation continues to reach the earth from the atomic cloud as it rises, the protection will be only partial. Further, as a result of scattering, the radiations will come from all directions.

PROTECTION FROM FALLOUT

Passive and Active Measures

12.63 Protection against the residual nuclear radiation from fallout presents a number of difficult and involved problems. This is so not only because the radiations are invisible, and require special instruments for their detection and measurement, but also because of the widespread and persistent character of the fallout. In the event of a surface burst of a high-yield nuclear weapon, for example, the area contaminated by the fallout could be expected to extend well beyond that in which casualties result from blast, thermal radiation, and the initial nuclear radiation. Further, whereas the other effects of a nuclear explosion are over in a few seconds, the residual radiation persists for a considerable time.

12.64 The protective measures which can be taken against sources of residual nuclear radiation fall into two main categories, namely, passive and active. Passive protection implies remaining in the contaminated area while taking all possible shelter from the gamma rays, in particular, emitted by the fission products in the fallout. As seen in Chapter IX, even the basement of a frame house can attenuate the radiation by a factor of about 10, and greater reduction is possible in a large building or in a shelter covered with several feet of earth.

12.65 There are two aspects of active protection which will be considered. One is evacuation, that is, removal of the population from a contaminated location to one that is either free from contamination or, at least, less contaminated. This action is by no means as simple as might at first appear, because it will generally involve passage, without protection, through contaminated areas. The resulting radiation exposure may thus be greater than if passive protective measures were taken without evacuation.

12.66 The other possible active procedure is decontamination after the fallout has settled. In most circumstances steps of one kind or another can be taken to decrease the amount of fallout in critical regions, e. g., roofs of houses and streets. Some of the more general methods of decontamination will be discussed later. It should be mentioned, however, that the procedures are inevitably hazardous, since they involve exposure of the operating personnel to fairly high levels of radiation.

12.67 The extent to which passive protection, evacuation, and decontamination should be practiced will depend upon the existing conditions and may vary widely from one case to another. It is impossible, therefore, to make any definite recommendations. The particular action taken must depend upon the judgment of responsible individuals, based on a knowledge of radiation intensities and various other factors, in addition to an appreciation of the characteristics of the residual nuclear radiation. A general guide to the possibilities may perhaps be provided by the discussion of a number of different circumstances in the following sections.

PROTECTIVE ACTION

12.68 It was recognized at the beginning of this chapter (§ 12.3) that the concept of the evacuation of populations from potential target areas was greatly complicated by the possible effects of fallout. Some aspects of the situation which must be considered before the movement of large masses of individuals can be undertaken will be outlined here. First, there is always a possibility of a sudden change in the wind pattern, so that the evacuees might be moving unwittingly into the path of the fallout. A somewhat similar circumstance might develop as the result of further explosions, at other points, after evacuation had started. In any case, accurate prediction of the fallout pattern is very difficult and requires detailed and continuous knowledge of the wind pattern over a large area and to great heights. Once the order for evacuation has been given, it would be virtually impossible to rescind it or even to change the main direction of personnel movement.

12.69 It may be that the best initial step is to take passive protective measures by seeking shelter in relatively closed structures. The gamma radiations from sources external to the body will then be appreciably attenuated. In order to prevent contaminated material from entering the body, a ventilation system with filters for removing particulate matter may be a desirable feature. However, in most buildings, sufficient air leaks through cracks or penetrates through the walls to permit satisfactory breathing even with the doors and windows closed. It is true that some of the fallout may enter at the same time, but it is believed, on the basis of the experience of the inhabitants of the Marshall Islands in the 1954 nuclear tests (§ 11.115, *et seq.*), that inhalation of the contaminated particles will not be a serious hazard.

12.70 Since the shelters may have to be occupied continuously for a period of from 2 to 7 days (or more), depending upon the level of the contamination outside, supplies of food and water will be necessary. These should be kept covered to prevent access of fallout particles. If water is available the exposed food can be washed free of contamination before being eaten (see § 12.97).

12.71 At locations relatively near to ground zero, the fallout will arrive soon after the explosion and the radiation dose rate will initially be high. It may then be necessary to wait several days before it is possible to come out of the shelter without risking a radiation dose of sufficient magnitude to cause severe injury. Leaving the shelter to evacuate the area or to start preliminary decontamination operations, will represent a calculated risk, which should not be undertaken, except in dire emergency, without the advice of a monitor familiar with the radiation situation in the surrounding area.

12.72 The farther a point in the path of the fallout is from the explosion, in the same general direction, the lower will be the initial radiation level and the shorter will be the duration of the passive protection phase. However, in any area where the contamination is at all serious, it will probably be necessary to spend the first day or two after the explosion sheltered from the residual gamma radiation. During the early stages, the activity of the fission products in the fallout is very high, but by the end of 49 hours or roughly 2 days, it will have decreased to about 1 percent of the value at 1 hour after the explosion.

12.73 It is impossible to indicate in advance at what value of the external dose rate it may be permissible to leave the shelter. Much would depend upon the next stage, e. g., evacuation or decontamination (or both), and how long it will take, as well as upon the total dose already received during the passive protection phase. The graphs given at the end of this chapter should aid in the estimation of the approximate doses that might be received under a variety of conditions. Such information is necessary before a decision can be made in any given situation.

12.74 At the beginning of this discussion it was supposed that an appreciable time elapses between the explosion and the arrival of the fallout. If, for one reason or another, there is no prior warning, the steps to be taken are essentially similar to those described above. The first action should be to seek optimum shelter, providing the maximum attenuation of the gamma radiation originating from outside sources, as quickly as possible. Speed is essential, since the radiation intensity from the fallout is extremely high soon after the explosion, but drops fairly rapidly in the course of time. After a few days, the shelter may be evacuated by a route which will involve a minimum radiation exposure.

12.75 It is appropriate to emphasize here that the presence of dangerous fallout may not be visible to the eye, and its detection requires the use of suitable instruments sensitive to nuclear radiations. It is true that some (although not all) of the fallout in the Marshall Islands, after the test shot of March 1, 1954, could be seen as a white powder or dust. But this may have been due to the light color of the calcium oxide (or carbonate) of which the particles were mainly composed. Had the material been somewhat darker in color and the particles somewhat smaller in diameter, it is possible that the fallout would not have been seen. Continuous monitoring, with instruments, for radioactive contamination would thus appear to be essential in all areas in the vicinity of the burst.

RADIOLOGICAL SURVEY

12.76 Soon after a nuclear explosion, general radiological surveys will have to be undertaken for a number of reasons. In the first place, it may be necessary for emergency crews to enter an area that is contaminated, and the level of the radiation intensity of the area must be known. The best, i. e., least contaminated, routes into and through the area should be determined. Further, persons sheltered within a contaminated region need radiological information from outside for the purpose of planning evacuation. In addition, highly contaminated areas must be located and marked to prevent accidental entry.

12.77. The most rapid method of estimating the extent of the radiation hazard in the early stages will probably be by means of an aerial survey. The great advantage of such a survey is that it can be carried out regardless of the debris, which would make roads impassable, or of the degree of contamination. Because of their long range in air, gamma rays from fission products on the earth's surface can be detected by sensitive instruments at a height of several thousand feet. Low-flying airplanes or helicopters carrying survey meters, which measure the gamma radiation dose rate, can fly over an affected area in accordance with a predetermined pattern. The initial flights might be at an altitude of 1,500 feet or so, where the radiation intensity is reduced by a factor of nearly 100 with respect to that on the surface (see Fig. 9.122). This could be followed by flights at lower levels, if necessary, for more exact identification of contaminated areas.

12.78 From the radiation intensities recorded by the survey instruments in the aircraft at a known altitude, it is possible to obtain a rough estimate of the dose rate, e.g., in roentgens per hour, which exists at the surface of the ground or water. The exact ratio between the reading in the air and the dose rate on the surface will depend on several factors, including the nature of the terrain and the time after the detonation at which the survey is made, because of the decrease in the energy of the gamma rays from fission products. If no more specific information is available, the data in Fig. 9.122 may be used to estimate the attenuation factor at a known altitude with reference to that on the ground.

12.79 The aerial survey is important because it can be made quickly and can provide valuable information which might be impossible to secure in any other way. Nevertheless, such a survey can serve only as a rough guide, and it must be supplemented by observations made on the ground. The information obtained from the measurements taken in the air will, however, help very greatly in planning the ground survey. In the first stages, the general extent of the contaminated area will be delineated, but later a more detailed investigation will be undertaken to determine the radiation levels at specific strategic points, to establish approximate dose-rate contours, and to locate "hot spots" of higher than average contamination.

12.80 It is important to remember that personnel performing monitoring operations will be continuously exposed to radiation, sometimes at high levels of intensity. As far as possible, they should be transported by vehicles which offer some degree of protection by attenuating the gamma radiation, e. g., by suitable shielding or distance. In order to avoid dangerous overexposure, the monitors must carry instruments which, at any time, indicate the total dose they have received. They will then know when they should return to headquarters, so that hitherto unexposed individuals may take their place and continue with the operation. If the results of a preliminary survey are available, some advance planning in this connection may be possible by using the graphs given at the end of this chapter.

DECONTAMINATION PROCEDURES[4]

12.81 Since radioactive material cannot be destroyed, decontamination inevitably involves transfer of the source of the radiation, e. g., fallout, from a location where it is a hazard to one in which it can do little or no harm. All decontamination procedures thus have two basic aspects: first, the removal of the contaminant, and second, its disposal. Unless proper consideration is given to the latter aspect, the whole process may do little or no ultimate good. Covering the contamination without moving it, e. g., with a depth of soil, would be effectively combining both operations into one.

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[4] An extensive treatment of decontamination methods and equipment will be found in the manual (TM–11–6) entitled, "Radiological Decontamination in Civil Defense," prepared by the Federal Civil Defense Administration.

12.82 Decontamination may be either gross, i. e., rough, or detailed. Gross decontamination is the rapid, partial removal or covering of contamination on a large scale. Its purpose is to reduce the radiation dose rate as quickly as possible to a point where personnel can use a piece of equipment or remain within an area for a limited period of time, at least. Subsequently, detailed decontamination, which is a lengthy and thorough process, may be carried out. As a general rule, decontamination cannot (and need not) be complete. However, the procedure should be carried to the point where the situation no longer constitutes a significant hazard under the particular conditions of use or occupation.

12.83 The decision to undertake decontamination will depend upon the circumstances, and must involve a calculated risk. Since there is always a certain degree of danger to the operating personnel, the procedure should be deferred as long as is reasonably possible, so as to take advantage of natural radioactive decay. In some cases urgent action may be necessary, and decontamination may have to be started while the radiation level is still high. Such a situation might be met by replacement of the workers with fresh, previously unexposed, crews at short intervals.

12.84 There are a few useful general principles relating to contamination and decontamination which should be borne in mind. Because of its particulate nature, the fallout will obviously tend to collect on horizontal surfaces. Such surfaces will thus be more highly contaminated than vertical surfaces. Hence, in preliminary decontamination, at least, the latter can be ignored. Most of the fallout particles can be readily removed either by washing with a stream of water or by sweeping, preferably with a vacuum cleaner to avoid inhalation of dust.

12.85 Gross decontamination can generally be performed in one or other of these ways. For smooth, e. g., painted and metallic, surfaces, wet (washing) methods may be used, but for porous materials, e. g., fabrics, brick, concrete, and stone, dry methods are to be preferred. Broadly speaking, water washing can be employed outdoors and on the exterior of vehicles, whereas vacuum sweeping is more suitable for the interiors of buildings and vehicles. Experimental tests of decontamination procedures have shown that the major portions of contaminating material can be removed by these simple methods. Only a small part of the contamination is strongly held and requires more drastic treatment, e. g., with chemicals or abrasives.[5]

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[5] Contamination due to neutron-induced activity is difficult to remove, but such contamination is of importance only near the explosion center (see § 9.18).

12.86 In a city, decontamination could be carried out by hosing the roofs of buildings and the streets with strong streams of water. The radioactive material would thus be transferred to the storm sewers, where it would represent only a minor hazard. As an alternative to hosing, the dose rate inside a building could also be reduced by covering the ground surrounding the building with uncontaminated earth or by removing the top layer of the ground to a distance with a bulldozer.

12.87 It is important to note, in connection with removal of contaminated earth, for the purpose just described or to provide a means of transit, that the gamma rays from fission products can travel considerable distances through air. For example, at 3 feet above the ground, roughly 50 percent of the dose rate received in the center of a large, flat, uniformly contaminated area comes from distances greater than 25 feet away, and about 25 percent from distances more than 50 feet away. Thus, complete removal of the contaminated surface from a circle 50 feet in radius would reduce the dose rate in the center to about one-fourth of its original value. However, if the contaminated earth were not completely removed, but just pushed to the outside of the circle, the dose rate would be considerably larger than one-fourth the initial value.

12.88 It is apparent, therefore, that if transit facilities are to be provided across open country which is contaminated over a large area, bulldozing the top few inches of contaminated soil to the sides will be satisfactory only if a wide strip is cleared. Thus, if the strip is 250 feet in width, the radiation dose rate in the middle will be reduced to one-tenth of the value before clearing. A similar result may be achieved by scraping off the top layer of soil and burying it under fresh soil. Something like a foot of earth would be required to decrease the dose rate by a factor of ten.

12.89 Badly contaminated clothing, as well as rugs, curtains, and upholstered furniture, would have to be discarded and buried or stored in an isolated location. When the radioactivity has decayed to a sufficient extent, or if the initial contamination is not too serious, laundering may be effective in reducing the activity of clothing and fabrics, to permit their recovery. Thorough vacuum cleaning of furniture might be adequate in some cases, but an instrument check would be necessary before further use.

Protection of Operating Crews

12.90 All personnel entering a contaminated area, to perform survey monitoring, decontamination, or other emergency operations, should adapt their clothing to prevent the entry of dust. The main purpose of this precaution is to minimize the possibility of "beta burns" as a result of direct contact of the fallout with the skin (see § 11.94). It should be remembered, of course, that clothing offers virtually no protection against gamma radiation, and so this hazard will still exist to an undiminished extent.

12.91 For dry operations, heavy pants and shoes are recommended, as well as cotton or canvas work gloves and a tight-fitting cap. In dusty areas it is advisable that the bottoms of the pants and the ends of the sleeves (over the gloves) be tied to prevent the entry of contaminated material. A scarf around the neck would also help in this connection. After a nuclear attack, the dust may arise from rubble, disturbance of the ground, etc., and may not necessarily be radioactive. Precautions to reduce inhalation of the dust in large amounts would be desirable, in any event. Consequently, in operations in which considerable quantities of dust may be encountered, goggles and a filter mask are advisable.

12.92 For wet decontamination operations, water-repellent clothing, rubber boots, and rubber gloves will be required (Fig. 12.92). They can be cleaned with a stream of water and used several times. provided there are no breaks or tears.

12.93 In addition to taking steps to prevent radioactive material from reaching the skin, workers will need protection from excessive exposure to radiation. For this purpose, each operator should carry a self-indicating meter, sometimes called an "organizational dosimeter," to record his total radiation exposure. Various types of dosimeters have been devised, and simple and reliable instruments, that can be produced cheaply and in large numbers, are available.[6]

12.94 Survey meters for the determination of radiation intensities (dose rates) will be required in order to detect regions of high activity and for estimating permissible times of stay in a contaminated area. As a general rule, instruments which measure the dose rate of gamma radiation will be satisfactory. In addition, special instruments sensitive to beta radiations are advantageous for such purposes as detecting beta-particle emitters on the body.

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[6] For a description of dosimeters and other radiation instruments developed by the Federal Civil Defense Administration, see "Radiological Instruments for Civil Defense," TB-11-20.

Figure 12.92 Water-repellent clothing for use in wet decontamination operations.

12.95 In connection with this aspect of personnel protection, there arises the question of the amount of nuclear radiation exposure that is permissible for those taking part in emergency operations. It is difficult, if not impossible, to supply an exact answer, for a great deal will depend upon the circumstances and the risks that must inevitably be taken.

12.96 In those phases of emergencies in which immediate action is required, it would rarely be possible to predict in advance the radiation dose that might be received as a result of such action. The consequences to the exposed individuals, would, therefore, be equally unpredictable. However, where the hazard could be estimated from available dose rate data, it might be possible to establish an approximate guide concerning permissible radiation exposures under emergency conditions.[7]

FOOD AND WATER

12.97 Foods that are properly covered or wrapped or are stored in closed containers should suffer little or no contamination. This will be true for canned and bottled foods as well as for any articles in impervious, dust-proof wrappings. If the contamination is only on the outside, all that would be necessary for recovery purposes would be the careful removal, e. g., by washing, of any fallout particles that might have settled on the exterior of the container.[8] Even vegetables could be satisfactorily decontaminated by washing. If this were followed by removal of the outer layers, by peeling, the food should be perfectly safe for human consumption. Unprotected food products of an absorbent variety that have become contaminated should be disposed of by burial.

12.98 As for food crops grown in contaminated soil, there is not yet sufficient information available. Some radioactive isotopes may be taken up by the plant, but their nature and quantity will vary from one species to another and also, probably, with the soil characteristics (§ 9.99). All that can be stated at the present time is that plants grown in contaminated soil should be regarded with suspicion until their safety can be confirmed by means of radiological instruments.

12.99 Most sources of public water supplies are located at a considerable distance from urban centers that might be targets of a nuclear attack. Nevertheless, appreciable contamination might result if the watershed were in the range of heavy fallout from a surface burst. Other possibilities are fallout particles dropping into a river or reservoir or the explosion of a nuclear bomb near a reservoir. In most cases it is to be expected that, as a result of the operation of several factors, e. g., dilution by flow, natural decay, and removal ("adsorption") by soil, the water will be fit for consumption, on an emergency basis, at least, except perhaps for a limited time immediately following the nuclear explosion. In any event, where the water from a reservoir is subjected to regular treatment, including coagu-

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[7] See, for example, "Emergency Exposures to Nuclear Radiation," Federal Civil Defense Administration Technical Bulletin (TB-18-1).

[8] Food could become contaminated even inside containers due to neutron-induced activity, but this is not likely to be important in locations where the packaged foodstuffs have survived the nuclear explosion intact (§ 9.25).

lation, sedimentation, and filtration, it is probable that much of the radioactive material would be removed.

12.100 Because soil has the ability to take up and retain certain elements by the process of "adsorption," underground sources of water will generally be free from contamination. For the same reason, moderately deep wells, even under contaminated ground, can be used as safe sources of drinking water, provided, as is almost invariably the case, there is no direct drainage from the surface into the well.

12.101 In some cities, water is taken directly from a river and merely chlorinated before being supplied for domestic purposes. The water may be unfit for consumption for several days, but, as a result of dilution and natural decay, the degree of contamination will decrease with time. It would be necessary, in cases of this kind, to subject the water to examination for radioactivity and to withhold the supply until it is reasonably safe. Assuming the contamination is due to fission products, the acceptable total beta (or gamma) activities under emergency conditions, for 10 and 30 day periods, respectively, are given in Table 12.101. Thus, if it is anticipated that the water will have to be used regularly for a period of 30 days, the maximum permissible activity is 3×10^{-2} microcuries per cubic centimeter (see § 9.125, *et seq.*). On the other hand, if it appears that the period will be shorter, water of proportionately higher activity may be consumed in an emergency.

TABLE 12.101

ACCEPTABLE EMERGENCY BETA (OR GAMMA) ACTIVITIES IN DRINKING WATER

	Activity	
Consumption period (days)	*Microcuries per cubic centimeter*	*Disintegrations per second per cubic centimeter*
10	9×10^{-2}	3×10^{3}
30	3×10^{-2}	1×10^{3}

12.102 The emergency limits for alpha particle emitters, such as uranium and plutonium, in water are appreciably less than those given in Table 12.101. However, it is expected that only in rare circumstances would these elements represent a contamination hazard in drinking water.

12.103 If the regular water supply is not usually subjected to any treatment other than chlorination, and an alternative source is not available, consideration should be given to the provision of ion-exchange columns (or beds) for emergency use in case of contamination.

Home water softeners might serve the same purpose on a small scale. Incidentally, the water contained in a domestic hot-water heater could serve as an emergency supply, provided it can be removed without admitting contaminated water.

12.104 In hospitals and on ships, sufficient water for emergency purposes could be obtained by distillation. It was found after the nuclear tests at Bikini in 1946, for example, that contaminated sea water when distilled was perfectly safe for drinking purposes; the radioactive material remained behind in the residual scale and brine. It should be emphasized, however, that mere boiling of water contaminated with fallout is of absolutely no value as regards removal of the radioactivity.

RADIATION DOSES AND TIMES IN CONTAMINATED AREAS

12.105 For the planning of defensive action, either active or passive, or of survey operations in an area contaminated with fission products, it is necessary either to make some estimate of the permissible time of stay for a prescribed dose or to determine the dose that would be received in a certain time period. The basic equations and the related graphs (Figs. 9.8 and 9.12) were given in Chapter IX, but the same results may be expressed in an alternative form that is more convenient for many purposes.[9]

12.106 If the radiation dose rate from fission products is known at a certain time in a given location, Fig. 12.106 may be used to determine the dose rate at any other time at the same location, assuming there has been no change in the fallout other than natural radioactive decay. The same nomogram can be utilized, alternatively, to determine the time after the explosion at which the dose rate will have attained a specified value. If there has been any change in the situation, either by further contamination or by decontamination, in the period between the two times concerned, the results obtained from Fig. 12.106 will not be valid.

12.107 To determine the total radiation dose received during a specified time of stay in a contaminated area, if the dose rate in that area at any given time is known, use is made of Fig. 12.107, in conjunction with Fig. 12.106. The chart may also be employed to evaluate the time when a particular operation may be commenced in order not to exceed a certain total radiation dose.

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[9] Devices of the slide-rule type, referred to in the footnote to § 9.11, are very useful for making rapid calculations of the kind described here.

12.198 Another type of calculation of radiation dose in a contaminated area is based on a knowledge of the dose rate at the time of entry into that area. The procedure described in the examples facing Fig. 12.107, which also require the use of Fig. 12.106, may then be applied to determine either the total dose received in a specified time of stay or the time required to accumulate a given dose of radiation. The calculation may, however, be simplified by means of Fig. 12.108, which avoids the necessity for evaluating the 1-hour reference dose rate, provided the dose rate at the time of entry into the contaminated area is known.

12.109 If the whole of the fallout reached a given area within a short time, Fig. 12.108 could be used to determine how the total radiation dose received by inhabitants of that area would increase with time, assuming no protection. For example, suppose the fallout arrived at 6 hours after the explosion and the dose rate at that time was R roentgens per hour; the total dose received would be $8R$ roentgens in 1 day, $11R$ roentgens in 2 days, and $13R$ roentgens in 5 days.

12.110. It is evident that the first day or so after the explosion is the most hazardous as far as the exposure to residual nuclear radiation from fallout is concerned. Although the particular values given above apply to the case specified, i. e., complete fallout arrival 6 hours after the explosion, the general conclusions to be drawn are true in all cases. The radiation doses that would be received during the first day or two are considerably greater than on subsequent days. Consequently, it is in the early stages following the explosion that protection from fallout is most important.

The nomogram shows the relationship between the dose rate at any time after the explosion and the 1-hour reference value (R_1). If the dose rate at any time is known, that at any other time can be derived from the figure. Alternatively, the time after the explosion at which a specific dose rate is attained can be determined.

Example

Given: The radiation dose rate due to fallout at a certain location is 8 roentgens per hour at 6 hours after a nuclear explosion.

Find: (*a*) The dose rate at 24 hours after the burst.

(*b*) The time after the explosion at which the dose rate is 1 roentgen per hour.

Solution: By means of a ruler (or straight edge) join the point representing 8 roentgens per hour on the left scale to the time 6 hours on the right scale. The straight line intersects the middle scale at 70 roentgens per hour; this is the 1-hour reference value of the dose rate (R_1).

(*a*) Using the straight edge, connect this reference point (70 r/hr) with that representing 24 hours after the explosion on the right scale, and extend the line to read the corresponding dose rate on the left scale, i. e., 1.5 roentgens per hour. *Answer*

(*b*) Extend the straight line joining the dose rate of 1 roentgen per hour on the left scale to the reference value of 70 roentgens per hour on the middle scale out to the right scale. This is intersected at 34 hours after the explosion. *Answer*

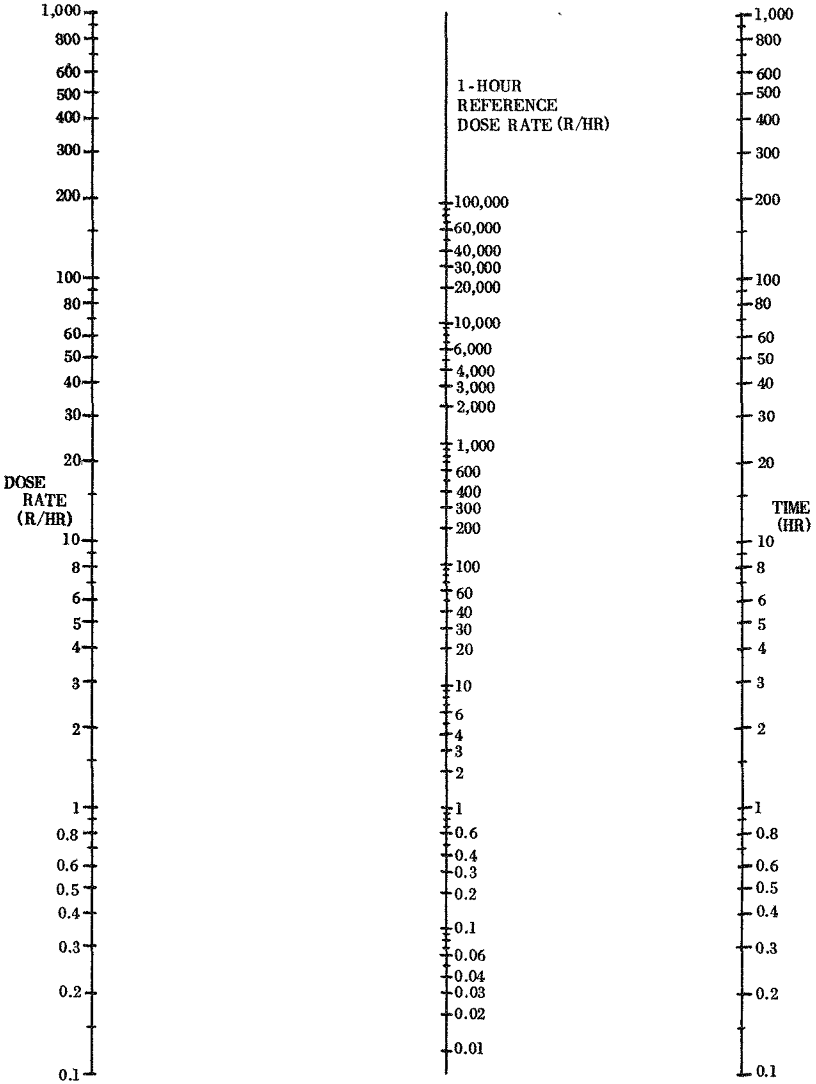

Figure 12.106. Calculation of dose rates from fission products in the fallout.

From the chart, the total radiation dose received from fission product fallout during any specified stay in a contaminated area can be determined if the dose rate at some definite time after the explosion is known. Alternatively, the time can be calculated for commencing an operation requiring a specified stay and a prescribed total radiation dose.

Example

Given: The dose rate at 4 hours after a nuclear explosion is 6 roentgens per hour.

Find: (*a*) The total dose received during a period of 2 hours commencing at 6 hours after the explosion.

(*b*) The time after the explosion when an operation requiring a stay of 5 hours can be started if the total dose is to be 4 roentgens.

Solution: The first step is to determine the 1-hour reference dose rate (R_1). From Fig. 12.106, a straight line connecting 6 roentgens per hour on the left scale with 4 hours on the right scale intersects the middle scale at 32 roentgens per hour; this is the value of R_1.

(*a*) Enter Fig. 12.107 at 6 hours after the explosion (vertical scale) and move across to the curve representing a time of stay of 2 hours. The corresponding reading on the horizontal scale, which gives the multiplying factor to convert R_1 to the required total dose, is seen to be 0.19. Hence, the total dose received is

$0.19 \times 32 = 6.1$ roentgens. *Answer*

(*b*) Since the total dose is given as 4 roentgens and R_1 is 32 roentgens per hour, the multiplying factor is $4/32 = 0.125$. Entering Fig. 12.107 at this point on the horizontal scale and moving upward until the (interpolated) curve for 5 hours stay is reached, the corresponding reading on the vertical scale, giving the time after the explosion, is seen to be 19 hours. *Answer*

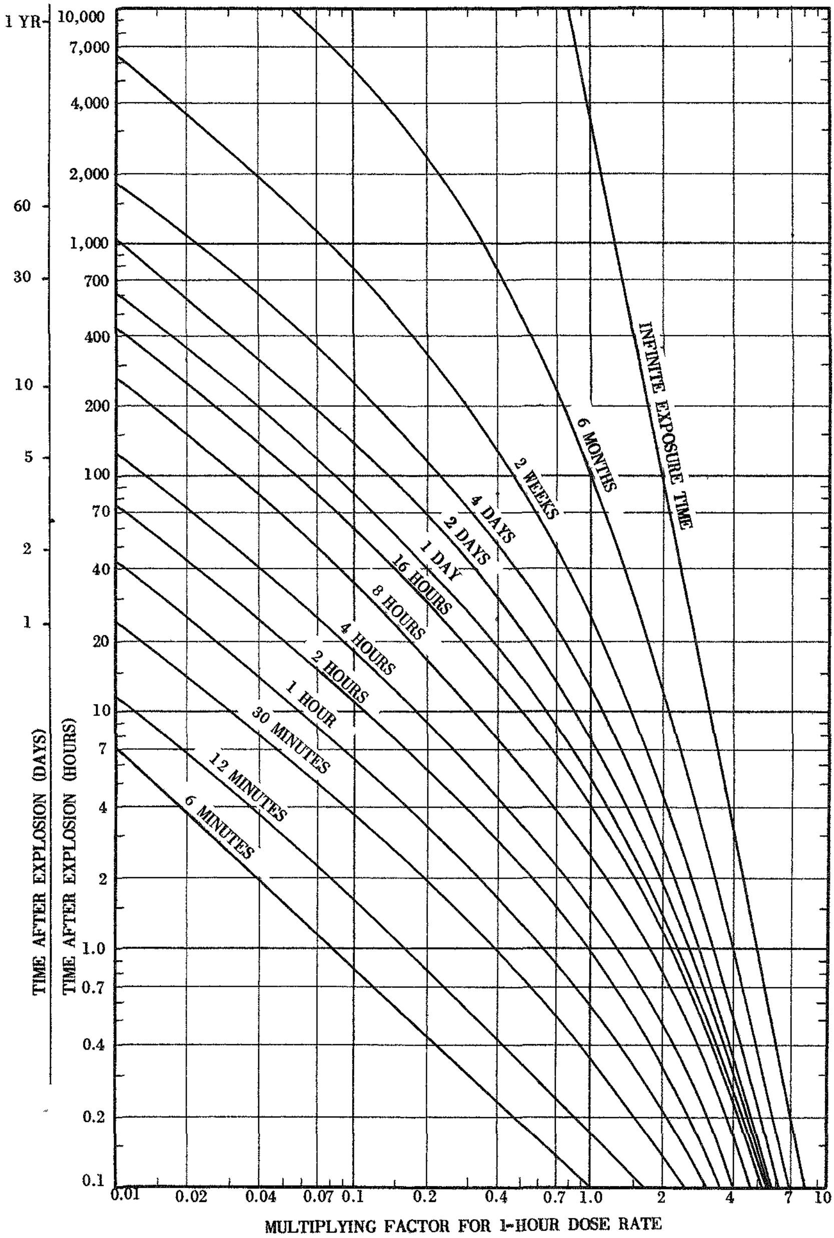

Figure 12.107. Total (accumulated) radiation dose due to fallout in a contaminated area based on 1-hour reference dose rate.

From the chart, the total radiation dose received from fission product fallout during any specified stay in a contaminated area can be determined if the dose rate at the time of entry into the area is known. Alternatively, the time of stay may be evaluated if the total dose is prescribed.

Example

Given: Upon entering a contaminated area at 12 hours after a nuclear explosion the dose rate is 5 roentgens per hour.

Find: (*a*) The total radiation dose received for a stay of 2 hours.
(*b*) The time of stay for a total dose of 10 roentgens.

Solution: (*a*) Start at the point on Fig. 12.108 representing 12 hours after the explosion on the vertical scale and move across to the curve representing a time of stay of 2 hours. The multiplying factor for the dose rate at the time of entry, as read from the horizontal scale, is seen to be 1.9. Hence, the total dose received is

$$1.9 \times 5 = 9.5 \text{ roentgens.} \quad \textit{Answer}$$

(*b*) The total dose is 10 roentgens and the dose rate at the time of entry is 5 roentgens per hour; hence, the multiplying factor is $10/5 = 2.0$. Enter Fig. 12.108 at the point corresponding to 2.0 on the horizontal scale and move upward to meet a horizontal line which starts from the point representing 12 hours after the explosion on the vertical scale. The two lines are seen to intersect at a point indicating a time of stay of about 2⅓ hours. *Answer*

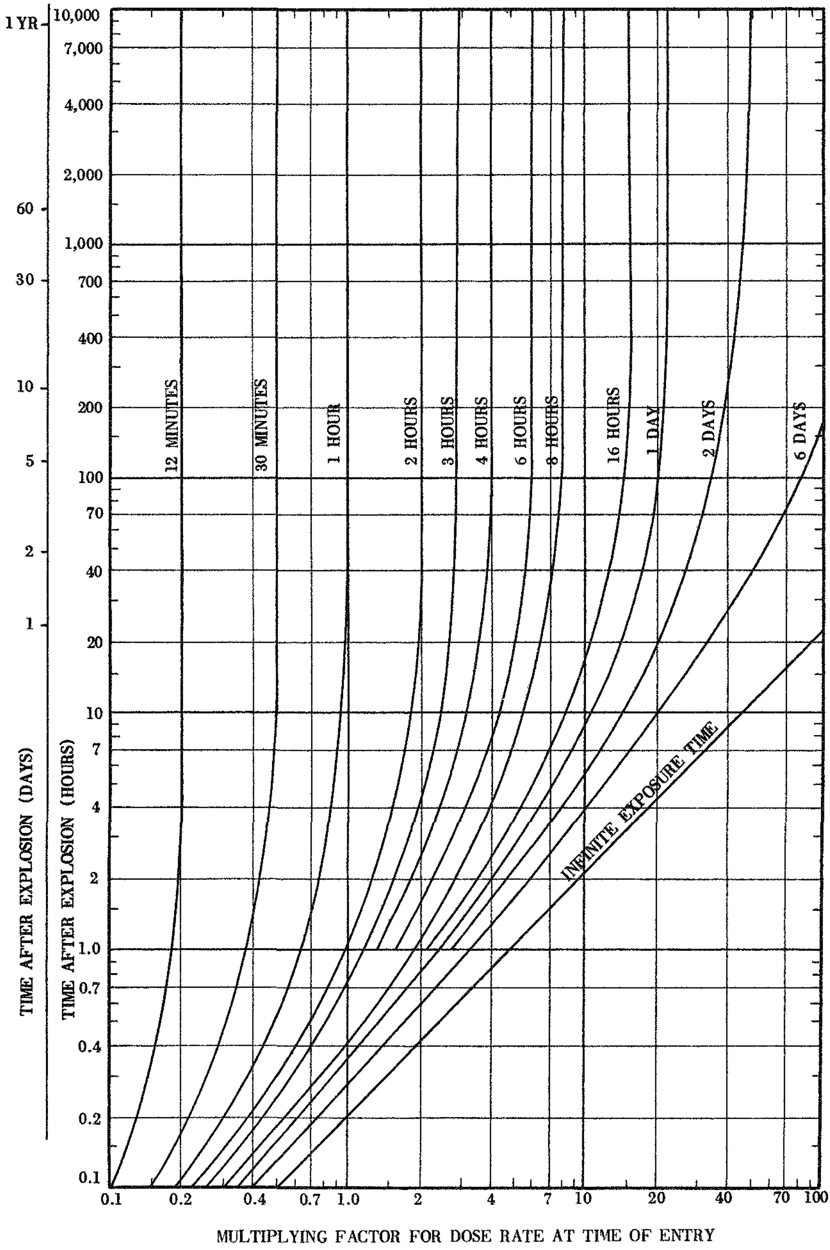

Figure 12.108. Total (accumulated) radiation dose due to fallout in a contaminated area based on dose rate at time of entry.

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